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It seems impossibile until it is done!

Circular Economy in the Agri-Food Sector: Going Beyond Sustainability

challenges and consumers' participation

Dipartimento di Agraria

Portici, Naples (ITA) - 2016

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This research was conducted under the auspices of the Department of Agriculture of the University of Naples Federico II - Italy

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Doctoral thesis

Submitted in fulfilment of the requirement for the degree of doctor at the University of Naples Federico II, College of Agriculture, within the XXVII doctoral program in Management and Valorisation of Agroforestry Resources. Thesis Committee appointed by the Academic Board to be defended in public in May 2016.

I dedicate this thesis
to my parents

Acknowledgements

Massimiliano Borrello is grateful to the Department of Agriculture of the University of Naples Federico II (ITA) for the financial support provided to conduct the research described in this thesis.

Massimiliano Borrello also gratefully acknowledges the Management Studies Group of Wageningen University (NL) for supporting him during a visiting period in the Social Sciences Group.

Massimiliano Borrello
March, 2016

Ringraziamenti

Desidero ringraziare il mio tutor Prof. Luigi Cembalo per il costante supporto datomi nell'indirizzare il mio percorso di dottorato. Lo ringrazio in primo luogo per avermi guidato nel mettere insieme i tasselli di un percorso di ricerca scientifica che mi consente oggi di sentirmi più maturo dal punto di vista professionale ed intellettuale. Le sue conoscenze, la sua determinazione nel perseguimento degli obiettivi e la sua predisposizione al confronto resteranno per me un modello a cui fare riferimento nelle mie esperienze lavorative future. Lo ringrazio inoltre per la componente umana che ha caratterizzato il lavoro fatto insieme. Il sincero interesse da lui rivolto alla mia crescita e alla valorizzazione delle mie attitudini, nonché l'affetto e la stima, hanno costantemente alimentato la fiducia e la serenità con cui ho portato a termine questo percorso.

Ringrazio il mio co-tutor Dr. Stefano Pascucci per il supporto datomi durante la mia permanenza presso l'Università di Wageningen e per aver potuto partecipare come discente alle sue lezioni. Il suo contributo concettuale è stato fondamentale per la maturazione del mio percorso di ricerca. Inoltre, il suo approccio non convenzionale alla didattica e la sua esperienza scientifica in un paese estero saranno per me in futuro un esempio di indipendenza e di realizzazione.

Agli altri coautori, Alessia Lombardi e Francesco Caracciolo, grazie per essere stati un importante punto di riferimento nella progettazione e nell'analisi dei risultati dei lavori presentati nella tesi.

Grazie a Roberto Freda per le tante ore trascorse insieme nello stesso ufficio, per la sua compagnia sempre discreta, per i consigli e per la disponibilità, minuzia e competenza dedicatemi nel risolvere ogni sorta di problema.

Ringrazio gli altri dottorandi Marco Lerro, Mario Amato, Marco De Gaetano, Carla Cavallo, Maria Raimondo e Luigi Mennella per tutti gli scambi di idee, per i momenti di leggerezza, e per la condivisione delle difficoltà e degli entusiasmi incontrati durante questo percorso di dottorato.

A tutti i cari, infine, il ringraziamento per la presenza, per quella reale e per quella sempre percepita. Li ringrazio per aver accettato la scommessa quotidiana di vedermi tornare dopo il lavoro di buono o di cattivo umore, a causa di avvenimenti rimasti per loro il più delle volte misteriosi. Li ringrazio per essere stati tutti osservatori attenti e partecipi, e per aver fatto per me più di quanto ci si aspetterebbe anche dall'amore più dedito.

«In all affairs it's a healthy thing now and then to hang a question mark on the things you have long taken for granted».

BERTRAND RUSSELL

Abstract

Circular economy is a new approach to the economy-environment pairing that has the potential of a revolution in the history of economic development models. This model is opposed to the traditional production pattern in which resources are extracted, used to produce goods and, eventually, landfilled. Circular economy supports a complete recycling of materials and implies a complete reorganization of production systems in which all steps of value chains are planned in order to use waste as input of new productions. Furthermore, it implies that consumers actively participate for closing the loops. The general objective of this study is the implementation of an assessment of the circular economy applied to agri-food supply chains. It is aimed to generate insights about the challenges that the circular economy will face in the next future. If main constraints for the implementation of the circular economy could be better understood, then this knowledge could be used to better design interventions to create first prototypes of circular supply chains and support initiatives aimed to improve the environmental performances of the agri-food sector. Our results are the outcome of a conceptual process leading to the definition of a set of macro-categories of challenges for the circular economy. Furthermore, we deeply investigated the point of view of consumers and it was possible to identify drivers influencing their participation to a program embedded into a hypothetic agri-food circular supply chain.

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INTRODUCTION

In the face of alarming signs of global resource depletion and growing population, the call for a new economic model is getting louder. The circular economy has been proposed by academics and international institutions as a new concept on which grounding the future global economic system. This thesis is aimed to provide a conceptual outline of the principles of the circular economy and to discuss possible implications of the new model in the domain of agri-food supply chains. The work is divided in three chapters followed by a summary of main findings.

Chapter 1 is aimed to provide the reader with the conceptual basis for understanding the context in which the idea of circular economy was developed. In paragraph 1.1, main issues regarding the impact of the mainstream linear model on environment, society and economy are discussed. Then, starting from the concept of sustainability, ecological economics paradigm is taken as a landmark for explaining the main theoretical approaches to the economy-environment pairing that have been developed during the last decades. Paragraph 1.2 introduces the circular economy by illustrating its origins, its principles, as well as its operational framework. Then, food losses and waste are presented as biological materials that have high potential for being used in the domain of a bio-based circular economy. At the end of the paragraph, after having mentioned main benefits and limits of the implementation of the circular economy in the agri-food sector, the objectives of the thesis are made explicit. Paragraph 1.3 is a review of main issues concerning food losses and waste produced during agri-food supply chains. Here, extent and implications of food losses and waste are discussed in order to stress the relevance of the implementation of the circular economy in the agri-food sector. Chapter 1 is concluded with a summary of materials and methods used for the investigations of the following chapters.

Chapters 2 and 3 of the thesis report two papers written by the author concerning the circular economy.
Chapter 2 regards the challenges related to the circular economy approach when applied to an agri-food supply chain. Starting from the description of a real supply chain, a circular version of that chain is depicted, from which the most relevant challenges for academics and practitioners are derived. The purpose of the chapter is to investigate the possibility of creating a circular based organization framework concerning the production/consumption/reuse of bread aiming at the goal ‘zero waste’. A potential network, in which seven actors and two radical technological innovations (PLA packaging and insects as feed) are involved, is designed in the chapter. Seven challenges for the transition to the bread circular supply chain are outlined. These challenges can be easily transposed to *filiéres* different from the one considered.
Chapter 3 is focused on the consumers’ aspect of the transition to the circular economy. A case-study is designed in the domain of agri-food supply chains for assessing the willingness of consumers to participate to the circular economy. Though there is growing social interest in ethical dimensions and sustainability issues related to food consumption, ensuring that people cooperate to create the circular model could require a significant effort. In this domain, in this chapter is illustrated a survey carried out through a structured questionnaire submitted to a representative sample of Italian Households (1,270 interviewees). A choice experiment was implemented in order to analyze alternative programs of participation based on the restitution of organic food waste by consumers to retailers in exchange for discounts on the purchase of animal products. The organic food waste returned enters in the production process of animal products through two alternative technologies (composting and insects as feed). This chapter depicts a comprehensive portrait of the potential participation of consumers to supply chains grounded on the principles of the circular economy.

The thesis is concluded with a summary of the main findings in which the results of the research are summarized. Here, implications for academics and policy makers are reported.

Chapter 1

CIRCULAR ECONOMY AND THE AGRI-FOOD SECTOR

1.1 Environmental collapse and theoretical approaches to sustainability

Post-industrial society of highly developed economies, emerging economies (the so-called BRICS, according to the international economics acronym)[1], as well as developing countries, are now facing, at the dawn of the third millennium, with serious and alarming global issues.

The world population is steadily increasing and is expected to grow from 7.2 to 9.6 billion people by 2050, with maximum increase of 50% in the 49 less developed nations (Table 1).

Table 1. World population, 1950, 1980, 2013, 2050, according to different variants.

	Population (millions)			*Population in 2050 (millions)*			
Development group or major area	*1950*	*1980*	*2013*	*Low*	*Medium*	*High*	*Constant-fertility*
World	2526	4449	7162	8342	9551	10868	11089
More developed regions	813	1083	1253	1149	1303	1470	1268
Less developed regions	1713	3366	5909	7193	8248	9398	9821

Source: UN, 2013

At the same time the Organization for Economic Co-operation and Development predicted the global Gross Domestic Product (GDP) to grow constantly until the 2050-2060 decade (OECD, 2014). These previsions entail an increased demand of consumable goods and obvious consequences on the exploitation of natural resources. The current extraction of construction minerals, ores and industrial minerals, fossil fuels and biomass is estimated to occur at a rate of 47

[1] BRICS: Brazil, Russia, India, China, and South Africa.

to 59 billion metric tons per year (2005 data) with continuous future increases (UNEP, 2011). The total amount of primary raw materials extracted is expected to reach 82 billion metric tons per year by 2020 (Table 2). Furthermore, in most countries, household consumption generates 60% of the total environmental impact of consumption and, considering the growing global population, a doubling of global wealth could lead to 80% more CO_2 emissions (UNEP, 2010). This would contribute to the already alarming environmental effects of global warming.

Already in 1798, Robert Malthus, English economist and demography expert, in his *An Essay on the Principle of Population*, predicted imbalances between the population increase and the availability of resources:

«The power of population is indefinitely greater than the power in the earth to produce subsistence for man».

Almost two centuries later, the world was already strongly influenced by the growth of population, the industrialization, as well as the scarcity of resources. The Club of Rome, in *The Limits to Growth*, identified in the exponential growth of economy and population, the outlook for a future crisis of global balance (Meadows et al., 1972).

Table 2. Global resource extraction, 1980, 2002, 2010, 2020.

	Resource extraction (billion tonnes)				*Resource extraction (% change)*
Resource categories	*1980*	*2002*	*2010*	*2020*	*1980-2020*
Metal ores	4	6	8	11	200
Fossil energy carriers	8	11	12	15	81
Biomass	12	16	16	20	67
Non-metallic minerals	16	22	27	36	116
Total amount	40	55	65	82	

Source: Ellen MacArthur foundation, 2012

The historian Eric Hobsbawm described in his masterpiece *The Age of*

Extremes (1995) the huge revolutions of the 20th century. More specifically he investigated the failures of 'the short 20th century', the time lapse between the beginning of the First World War and the collapse of the Soviet Union. With regard to criticisms of both economic and technological development, he stated:

«A rate of economic growth like that of the second half of the Short Twentieth Century, if maintained indefinitely (assuming this to be possible), must have irreversible and catastrophic consequences for the natural environment of this planet, including the human race which is part of it. It will not destroy the planet or make it absolutely uninhabitable, but it will certainly change the pattern of life on the biosphere, and may well make it uninhabitable by the human species as we know it in anything like its present numbers. Moreover, the rate at which modern technology has increased the capacity of our species to transform the environment is such that, even if we assume that it does not accelerate, the time available to deal with the problem must be measured in decades rather than centuries».

So, throughout the last two centuries, the belief in a strict connection between the carrying capacity of our planet and the economic growth (on one side) and the probable negative effects of these variables on human society (on the other side) have been a reason of discussion and concern.
Jared Diamond (2005), in his *Collapse: How Societies Choose to Fail or Succeed*, investigates the causes leading past and present societies to dramatic failures and focus his attention on the irrational exploitation of natural resources. By analogy, Diamond claims that modern industrial society, to a much larger extent, is heading towards a similar collapse. According to Randers (2008), the long-lasting overshooting of the carrying capacity of natural ecosystems could erode the productivity of resources of our planet. The break of 'Gaia' mechanisms (Lovelock and Margulis, 1974) by means of intensive human impacts could jeopardize the capability of the Earth to

regenerate resources and to absorb pollutants. This could lead to a period of decades in which human welfare would drastically decline because of decreasing of income and life spans, increasing mortality, famines and other forms of deprivation. In order to identify parameters to state that human race would be passing through collapse, Randers (2008) define a collapse as ‘global’ if: i. it affects at least 1 billion people, who lose at least 50% of something they hold dear, within a period of 20 years. The one billion people need not be located in one area. The collapse would be global if all rich individuals in the world (income above 30.000 USD per person-year) agreed that their quality of life had declined by one half over several decades; ii. the decline need not be loss of income: it could be the loss of anything the citizens hold dear (like freedom, the ability to travel, or physical safety); and iii. the decline must be sufficiently abrupt that the population remembers how things were in the good old days—‘before the collapse’.

Reasons determining past cultures to reach deep crisis without ‘battening down the hatches’ may be identified in the so-called ‘creeping normality’ (Diamond, 2005). This expression refers to the pattern determining a radical transformation to be accepted as normal just because it is happening too slowly to be perceived. In other words, Diamond (2005) sustains that a revolution can be accepted as the usual condition if it happens gradually, in unnoticed increments, when it would be considered as intolerable if it occurred abruptly or in a short period. The same idea is well summarized through the ‘green algae’ theorem (Latouche, 2009)[2]:

«Encouraged by the local farmers' excessive use of chemical fertilizers, a bloom of green algae set up home in a very big pond one day. Although its annual growth rate was rapid - it doubled in size every year - no one was worried. Even if it did double in size every

[2] For other similar examples, see also the ‘boiled frog’ metaphor and the ‘camel’s nose’ metaphor.

year, only 3% of the pond's surface would be covered in twenty-four years. People did begin to get a little worried when it had colonized half the surface. At that point, eutrophication became a distinct possibility: sub-aquatic life might be asphyxiated. The problem was that, although it had taken several decades to reach this point, it would now take only one year for the lake's ecosystem to die completely».

The ‘devotion’ to the traditional way communities consider their own relationship to the Earth, determines a dangerous inertia that limits any opportunities for change (Page, 2005). According to the *status quo* bias theory (Samuelson and Zeckhauser, 1988), a preference for the present condition leads the current baseline to be taken as a reference point, and any change is noticed as a loss. In this terms, our society seems to be devote to the current well-established economic model. Since its origin, our industrial economy has been based on the same production and resources management model. Market economy evaluates the development of a country by using GDP within a quantity-oriented economic growth model. Qiao and Qiao (2013) summarize the priorities of this system with the expression ‘three high and one low’, referring to: high resources exploitation, high consumes, high waste production and low efficiency. Materials are harvested or extracted, then they are used to produce goods to be sold to the customers or consumers, who finally get rid of them after their use. The ‘take – make – dispose’ framework (Ellen MacArthur Foundation, 2012), also called ‘resources – manufactured product – pollution emissions’ (Qiao and Qiao, 2013), is fundamentally characterized by linearity (linear economy): resources and processes follow only one direction along the value chain. In other words, products are trapped in a ‘cradle to grave’ life cycle (McDonough and Braungart, 2002), in which little or nothing re-enters the production chain.
Linear economy framework can be summarized in a five steps process: raw materials extraction, consumable goods production,

distribution, consumption and waste disposal (Figure 1). In order to reach economic efficiency, this model has been always pursued by augmenting natural resources exploitation, especially fossil fuels (Ayres et al., 2003), and avoiding to pay indirect costs of manufacturing activities, the so-called 'externalities' (Ellen MacArthur foundation, 2012). Externalities 'refers to situations when

Figure 1. Scheme of the linear economy.

the effect of production or consumption of goods and services imposes costs or benefits on others which are not reflected in the prices charged for the goods and services being provided'[3]. To illustrate, imposed costs, also called negative externalities, are the environmental costs of production activities. Society is given the charge to pay the costs of pollution and of the depletion of natural resources. Hardin (1968), in his well-known article *The Tragedy of the Commons*, investigated issues concerning common goods[4] and laconically summarized the explanatory logic of negative externalities:

«The owner of a factory on the bank of a stream – whose property extends to the middle of the stream – often has difficulty seeing why it is not his natural right to muddy the waters flowing past his door».

Therefore, in the linear economy, the criteria that regulate the exploitation of resources and the emission of waste follow the rules of common goods. As a consequence, this system generates remarkable losses of resources along the value chain and is unsustainable and inefficient (Ellen MacArthur Foundation, 2012). To illustrate, the

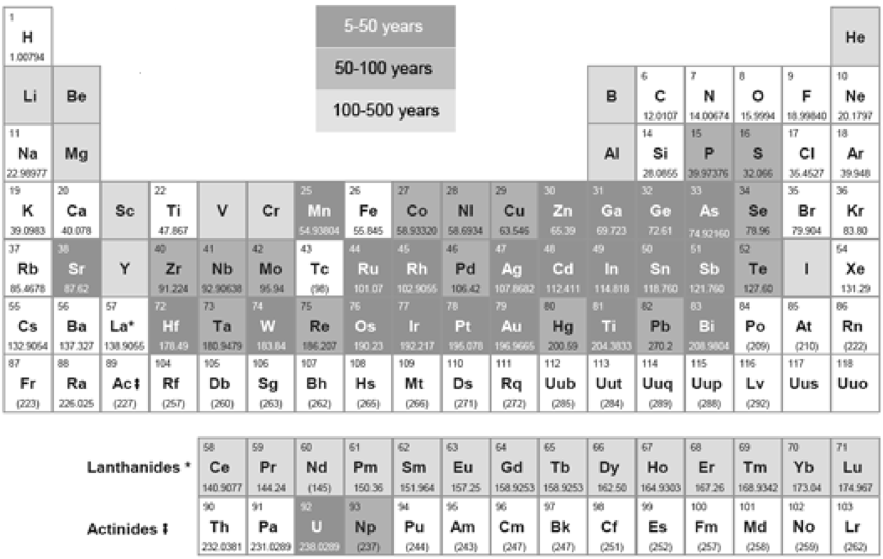
[3] http://stats.oecd.org/glossary
[4] For a definition of 'common good', see: http://www.britannica.com/topic/common-good

Sustainable Europe Research Institute (SERI) estimates 21 billion metric tons of materials per year entering the productive processes of OCSE countries without being physically incorporated in final products [5]. Moreover, the extraction of raw materials and the exploitation rate of fossil fuels exceed the potential of our planet to regenerate them, thus reducing the natural capital (McNicoll, 2005).
Figure 2 and Figure 3 illustrate previsions about the running out of natural elements and the unbalance with their rate of recycling. This non conservative use of resources entails the reduction of ecosystem services, that are the benefits gained by humans from ecosystems[6]. According to the Millennium Ecosystem Assessment (2005), a survey of the effects of human activities on the environment, ecosystem services are being used at unsustainable rates. Furthermore, greenhouse gases produced by human activities contribute to global warming and to the depletion of ecosystems (IPCC, 2007). In spite of the concerns of international institutions about potential consequences of the greenhouse effect, CO_2 global emissions originated from industrial activities and from the combustion of fossil fuels is still increasing (Figure 4). The unbalance between resources exploitation and the capacity of our planet to regenerate them is synthetically expressed by the ecological footprint, a standardized measure that represents the biologically productive land and sea area that would be necessary to a human community to live sustainably (Wackernagel and Rees, 1998).. To date, mankind uses the equivalent of 1.3 planet Earth per year, resulting in a requirement of one year and four months to regenerate resources exploited in just one year [7]. Furthermore the use of resources is not fairly distributed among countries. Developed countries take advantage of resources belonging

[5] http://www.materialflows.net/home/
[6] These include ‘provisioning services’ such as food, water, timber, and fiber; ‘regulating services’ that affect climate, floods, disease, wastes, and water quality; ‘cultural services’ that provide recreational, aesthetic, and spiritual benefits; and ‘supporting services’ such as soil formation, photosynthesis, and nutrient cycling (Millennium Ecosystem Assessment, 2005).
[7] http://www.footprintnetwork.org

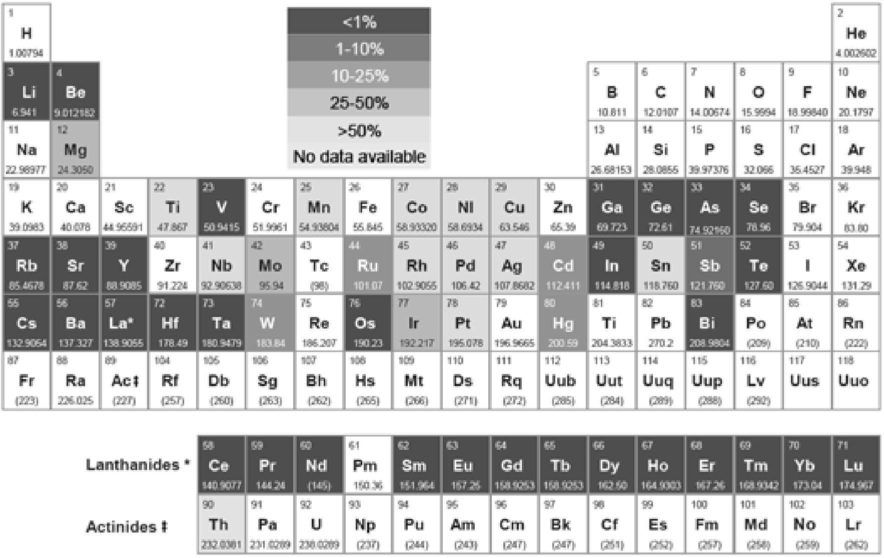
to developing ones, generating serious political, economic and social consequences (Bannon and Collier, 2003).
The inefficiency of linear economy can be also noticed at the stage of waste disposal. In 2010, only 40% of the 2.7 billion metric tons of waste generated by production processes was reused, recycled or composted and digested[8]. The disposal of waste into landfills implies the loss of the residual energy incorporated inside this waste. Even incineration or recycling save only a little amount of this energy (Ellen MacArthur Foundation, 2012). Furthermore, both the latter processes are not always feasible, because of products containing toxic materials or that are not designed to be recycled.

Figure 2. Periodic table of elements showing the years remained until depletion of known reserves of natural elements[9].



8 http://epp.eurostat.ec.europa.eu/cache/ITY_PUBLIC/8-04032013-BP/EN/8-04032013-BP-EN.PDF
9 Adapted from: http://reports.weforum.org/toward-the-circular-economy-accelerating-the-scale-up-across-global-supply-chains/mounting-pressure-on-resources/

Figure 3. Periodic table of elements showing the current rates of recycling of natural elements[10].



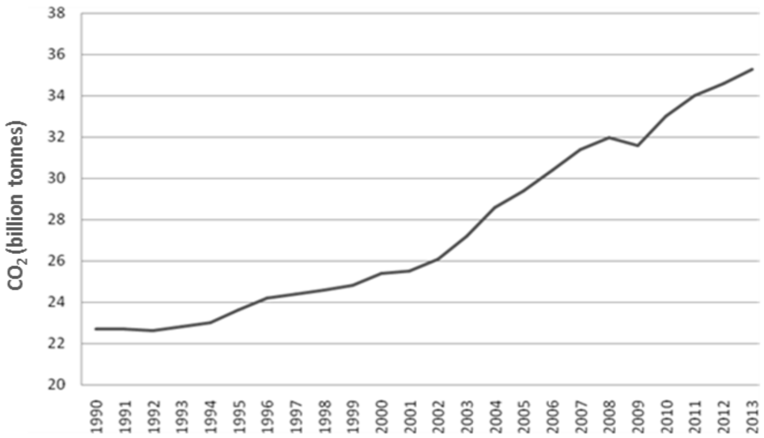
In the best possible scenario, when products don’t end up in landfills, they are recycled through ‘downcycling’ processes, losing most of their intrinsic value (McDonough and Braungart, 2002).
Linear economy influences also what happens at the stage of consumption and characterizes the relation between consumers and the items produced. Except for domestic recycling, consumers have no responsibility towards the product and may be considered mere intermediaries between retailers and waste collection. The condition of consumers was bitterly summarized in 1955 by Victor Lebow, an analyst of American markets:

«Our enormously productive economy demands that we make consumption our way of life, that we convert the buying and use of goods into rituals, that we seek our spiritual satisfactions, our ego

[10] *Ibidem*

satisfactions, in consumption. […] We need things consumed, burned up, worn out, replaced, and discarded at an ever increasing pace. We need to have people eat, drink, dress, ride, live, with ever more complicated and, therefore, constantly more expensive consumption».

Figure 4. Trends in global CO_2 emissions, 1990–2013.



Source: Olivier et al., 2014

In such a system, the decisions of companies are determined by the 'planned obsolescence', that is the policy of planning products with an artificially limited useful life in order to impose a continuous demand of new products and to increase the profits. Products are designed without considering refurbishment or intentionally making it not convenient. In 1933, after the Great Depression of 1929, the American economist Bernard London, in his *The new Prosperity*, even suggested that the planned obsolescence would have been indispensable to overcome the economic crisis. Unfortunately, the scientific literature in economics, still accommodate partisans of planned obsolescence (Strausz, 2009). In addition, 'perceived obsolescence' rules the choices of consumers. Consumers are influenced by a society constantly flooded of new products and they perceive as old-fashioned items still intact and functioning. Latouche

(2009) claims:

«Advertising makes us want what we do not have and despise what we already have. It creates and re-creates the dissatisfaction and tension of frustrated desire».

This implies a drive to consume that is far superior to the actual necessities of people. One needs only to consider that in the medium and high income nations, a huge amount of products are not used for the purpose they had been bought originally (Ellen MacArthur Foundation, 2013). A typical example of this phenomenon can be found in the apparel sector where lots of clothes are worn only a few times before being wasted or forgotten. For instance, UK citizens have in their wardrobes clothes that have not been used for one year and that are worth USD 5 billion (WRAP, 2012).
Eventually, the inefficiencies of the linear economy are starting to be noticed also at the company level. Companies are now facing with the diminished economic convenience of the exploitation of primary raw materials. They are more exposed to the risks determined from the scarcity of resources. To illustrate, higher and volatile prices and the interruption of supplies are already a reason of concern for the market of natural resources (Ellen MacArthur Foundation, 2012). In order to remain competitive while facing the challenge related to the scarcity of resources, companies have to find the way to address the green imperative. Table 3 summarizes main impacts of the linear economy in different areas.
Linear economy model is now facing several obstacles. The linear system results by now both economically and ecologically inefficient, being too detrimental in terms of supply of secure resources and of wastage of materials (Mathews and Tan, 2011). Environmental issues related to pollution and waste production, the reduced availability of natural resources and the growing demand of these resources due to the increasing world population are hard challenges. These challenges must be faced through new approaches to the economic system (Ellen

MacArthur Foundation, 2012). New strategies will probably lie on the minimization of waste, on the design of green products, as well as on the technological innovation (Menguc and Ozanne, 2005).

Table 3. Impacts of linear economy on environment, society and economy.

	Impacts
Environment	Externalization of pollution costs
	Overexploitation of natural resources
	Depletion of ecosystem services
	Global warming
	High ecological footprint
	Overproduction of waste
	Low or even not existent recycling of materials
Society	Unequal distribution of resources among countries
	People not feeling responsible of their consumes
	Perceived obsolescence
	Overconsumption
Economy	High and volatile prices of resources
	Interruptions of supplies
	Planned obsolescence

Source: elaboration from the text

In spite of this awareness, pessimistic theories of Thomas Malthus (1798) about the supply of resources and the growth of population have bumped during the time into some criticisms. The American philosopher Ralph Waldo Emerson (1875) contested Malthus's statements in his work *Resources*:

«Malthus, when he stated that the mouths went on multiplying geometrically, and the food only arithmetically, forgot to say, that the human mind was also a factor in political economy, and that the augmenting wants of society would be met by an augmenting power of invention».

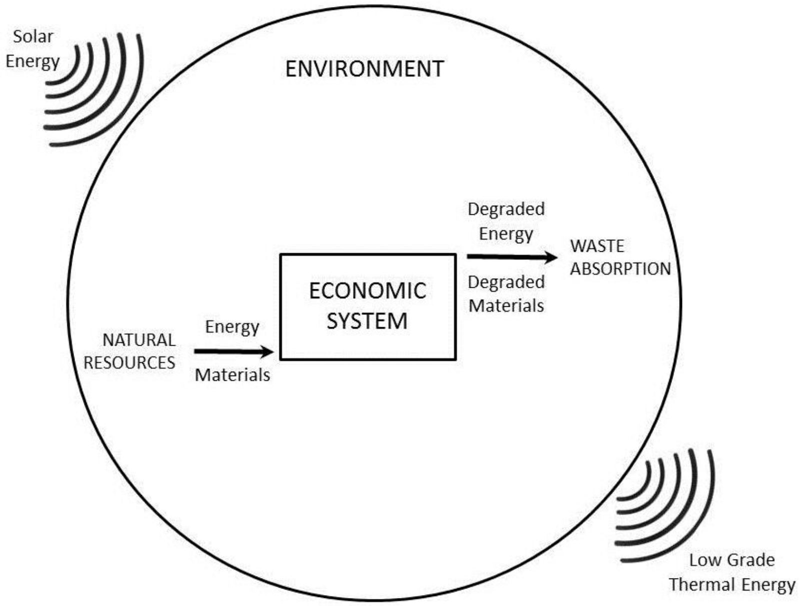
Hence, the power of invention of human beings is considered by Emerson as the instrument societies should use in order to solve crises and situations of need. Page (2005), analyzing the possibilities of collapse of our society advanced by Diamond (2005), wondered:

«…should the fact that civilizations on marginal land collapsed be seen as a warning that our modern, technologically sophisticated, and integrated economies are bound to collapse?».

Our insights to give a convincing negative answer to this question or to confute Diamond's catastrophic hypothesis are not sufficient. Furthermore, the challenges of sustainability are connected with and intensified by the lock-ins existing in many areas. To illustrate, current economic model is highly related to established business models, technologies, life styles, supply chains, as well as organizational, regulatory, institutional and political structures (Markard et al, 2012). Nevertheless, the possibility of our society to change its model by developing new systems for resources management has been considered in the research and institutional landscape.

In the light of both concerns about the depletion of resources and the previsions of the Club of Rome (Meadows et al., 1972), sustainable development model has been, in the past decades, the focal point of international environmental policies. The United Nations World Commission on Environment and Development, in the report *Our Common Future* - better known as the *Brundtland Report* - defined sustainable development as follows: 'development that meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987). Therefore, this model assumes that human economic development should be compatible with the preservation of the environment and of natural resources for future generations. For doing this, it should be based on the balance between human needs and nature. Figure 5 shows a scheme of inputs and outputs resulting from the integration of the economic system into natural ecosystems. Solar energy supports, through the photosynthesis, natural ecosystems. Both materials and energy that result from photosynthesis are used as units of production for the economic system. Once transformed natural inputs into goods and services, outputs come out from the economy as waste and pollutants. When waste and pollution exceeds the limit of the environment to act as a 'sink', long-term damage occurs. Furthermore, when extraction exceeds the regeneration rate of resources, the 'source' function of ecosystems is compromised.

Figure 5. Environment and economic system: input and outputs.



Source: elaboration from the text

As a consequence, according to sustainable development principles: i. renewable resources should not exceed their regeneration rate; ii. non-renewable resources exploitation rate should be compensated by the production of renewable ones able to substitute the formers; and iii. pollutants emissions should not exceed the buffer capacity of the

environment. To summarize, sustainable development is founded on the assumption that the anthropic impact on natural systems should not exceed the carrying capacity of nature.
However, at the time of the *Brundtland Report* how this goal should be achieved wasn't really clear. As Hobsbawm (1995) remarks:

«...the term ('sustainable') was conveniently meaningless and, in the long run, a balance would have to be struck between humanity, the (renewable) resources it consumed and the effects of its activities on the environment. Nobody knew and few dared to speculate how this was to be done, and at what level of population, technology and consumption such a permanent balance would be possible».

In order to underline the vagueness of the roadmap suggested in the *Brundtland Report,* Hobsbawm exacerbate the concept by using the hyperbolic term 'meaningless' as an attribute for 'sustainability'. Given its broad diffusion, we will keep using the term 'sustainability'. Nevertheless, in this thesis, this term will be referred to its proper ecological meaning, namely the capacity to endure (Fogarty et al., 2013).
In spite of any linguistic speculation, finding the way to achieve the purposes of sustainable development by means of the transition to a novel and revolutionary economic model, radically innovative in comparison with the one of the linear economy, has been the crucial point of some researchers during the last fifty years. According to Graungaard (2014), radical innovations can occur in 'niches', suited for the experimentation of new technologies, user practices and regulatory structures, because of a greater flexibility in comparison with the main regime. Transition research is focused on understanding how social, economic, political and cultural challenges can be overcome in order to make the niche become the regime. Transitions research is aimed to summarize the strategies of many transition pathways and 'uncovering how socio-technical configurations that might work become configurations that do work' (Graugaard, 2014).

In this domain may be included the scientific branch of sustainability transitions, in which a multiform landscape of strategies walk along parallel pathways in order to reach the goal of sustainability. More specifically, according to Markard et al. (2012):

«Sustainability transitions are long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption».

These transformation processes, as the sustainable development model claims, should assume a balanced coexistence of anthropic and natural systems. The assumptions hidden behind this need is related to the scientific explanation of Malthusian postulates. Malthus' intuition about physical limits of economic growth was supported at a later stage by Sadi Carnot (1824) through the second law of thermodynamics. Since transformations of energy from one form to another are not completely reversible - thus generating entropy – an economy based on these transformations is inevitably conditioned. The second law of thermodynamics, that explains the entropy of the physical universe, can be applied to the nature of the economic process. As a consequence, human economic activity may be described as a dissipative system in which man is accelerating the entropic depletion of natural resources.
However, only starting from the seventies of the last century the problem of the integration of ecology into economics began to be submitted to deeper investigation. Nicholas Georgesçu-Roegen was the forerunner who, as first, identified 'bio-economic' implications of the entropy law (1971). Bio-economics is a school of economics that applies the laws of thermodynamics to economic theory. According to Georgesçu-Roegen, traditional economics ignores entropy and doesn't consider that time and matter and energy transformations are irreversible. Hence, no attention is given to the problem of waste and pollutants that don't reenter production processes. This problem is

instead fundamental for those who claim that an unlimited growth in a limited world is not possible and the need of switching to the bio-economy model. In this context, finding its basis in Georgesçu-Roegen's theories, a new branch of economics, namely 'ecological economics' began to rise. Ecological economics differs from 'environmental economics' (Figure 6), the branch of economics that applies neoclassical thought to environmental issues, so considering environment as a subset of human economy. Neoclassical economics doesn't consider the contributions of nature to the creation of wealth by means of ecosystem services. On the contrary, ecological economics considers economy as a subfield of ecology and explicitly focuses on long term environmental sustainability. According to Qiao and Qiao (2013):

«Based on ecological principles, this theory holistically studies the mutual influence and restraint between ecosystem and productivity system, and the combination of ecology and economy, reveals the essential connections between the nature and the society, changes traditional patterns of production and consumption, and saves all available resources».

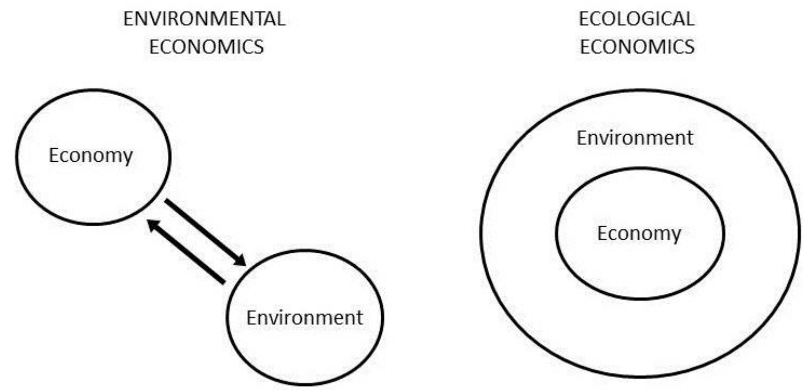
Hence, ecological economics may be considered an interdisciplinary field of research aimed to investigate the interdependence and co-evolution of human economies and natural ecosystem over time and space (Xepapadeas, 2008).
Using ecological economics as a starting point, one of the theoretical approach to the environment-economy pairing is the 'steady-state economy'. The steady-state economy is a physical concept in which non-physical and physical components are considered. Non-physical components of an economy can grow indefinitely whereas physical ones are constrained and endogenously given. The objective of a steady-state economy is to fix physical components like the extraction of natural resources and human population at a sustainable scale that does not exceed ecological limits. According to Herman Daly (1974),

main theorist of this approach:

«A steady-state economy is defined by constant stocks of physical wealth (artefacts) and a constant population, each maintained at some chosen, desirable level by a low rate of throughput».

The throughput are the inevitable positive flows of physical components that have to be maintained in order to preserve the stocks.

Figure 6. Environmental vs ecological economics.



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Though this model features stable population and stable consumption that remain at or below carrying capacity, it has been widely criticized within ecological economics academic circles. Even if he was a scholar of Georgesçu-Roegen, main criticisms concerning Daly's theory are related to thermodynamics. According to the second law, entropy increases in an isolated system, so that a steady state is an entropic impossibility (Kerschner, 2010).
The work of Georgesçu-Roegen has been influential also for the development of the concept of 'de-growth' (Latouche, 2009). De-growth has its intellectual roots in the denounce of the 'inner workings' of modernity (*e.g.* advertising, bureocracy, power of

technique) (Charbonneau, 1969). It may be defined as 'an equitable and democratic transition to a smaller economy with less production and consumption' in opposition to 'the neoliberal 'mantra' of the supremacy of markets for fostering prosperity through ever growing efficiency' (Martínez-Alier et al., 2010). The idea of de-growth may be considered, rather than a systematic economic model, a political and philosophical manifesto rooted in and aimed to a postmodern humanism. With regard to this, the Italian philosopher Umberto Galimberti in *I miti del nostro tempo* (2009) has speculated about sociological implications of global economy and of the era of technique. He argues:

«...did we become mere instruments of the ideology of growth, that use us as moments of its organization, mere and insignificant rings of its chain, or, if we prefer, essential means, even if among the most interchangeable, within an economic apparatus an hand in itself?»[11].

In this domain, Serge Latouche, French economist and philosopher and main partisan of de-growth, summarizes his sociological end ecological perspectives in his main work *Farewell to Growth* (2009)[12]:

«The upheavals required to build an autonomous de-growth society can, in contrast, be seen as the systematic and ambitious articulation of eight interdependent changes that reinforce one another. They can all be synthesized into a 'virtuous circles' of eight 'R's: re-evaluate, re-conceptualize, restructure, redistribute, re-localize, reduce, re-use and recycle. We can immediately see which values have to be promoted, and which values must take precedence over the dominant

[11] Original text: «*…siamo noi diventati semplici strumenti dell'ideologia della crescita, la quale ci impiegherebbe come momenti della sua organizzazione, semplici anelli insignificanti della sua catena, o, se preferiamo, mezzi imprescindibili, ma anche fra i più intercambiabili di qualsiasi altro mezzo, all'interno di un apparato economico diventato fine a se stesso?»*.
[12] The chapter of this quote has the provocative name *A concrete Utopia*.

values (or absence of values) of the day. Altruism should replace egotism, and unbridled competition should give way to cooperation. The pleasure of leisure and the ethos of play should replace the obsession with work. The importance of social life should take precedence over endless consumerism, the local over the global, autonomy over heteronomy, an appreciation of good craftsmanship over productivist efficiency, the rational over the material, and so on».

These political slogans, even being charming and ethically embraceable, still dissimulates a lack of investigation about potential effects on markets, employment and financial systems of de-growth. There are not formalized principles of de-growth recognised in the academic and political landscape. Moreover, how much downsizing the economy should need and how such de-growth should be rationally put into practice is still unclear.

As illustrated, theoretical approaches to the implementation of bio-economics and ecological economics to reality are still under debate. They often lack of both unanimity among academics and empirical validation. However, these approaches summarize the substrate on which research is feeding in this field of inquiry. In spite of any assumption regarding the dissipation of energy, the idea of Daly (1974) about a long-lasting equilibrium in the domain of physical components of biosphere is fundamental. Furthermore, the expressions 'reduce', 're-use', 'recycle' and 'endless consumerism' used by Latouche recall ecological economics principles and let us infer the theoretical direction that alternative tendencies to the mainstream economy are walking through in order to achieve the transition to sustainability.

1.2 Waste=Food: opportunities for agri-food supply chains in the framework of the circular economy

The holistic approach of ecological economics to the economy-environment system and the principles of sustainable development have found during the last years a specific implementation in the circular economy. The expression ‘circular economy’ was born in opposition to the traditional economy, that is considered linear. In the new framework, the economy is transformed from a system depending on the continuous exploitation of resources, to another one whose development depends on the recycling of natural resources and on the principle ‘waste=food’. The concept of circular economy is a revolution in the history of the evolution of economic development models. It was first introduced with regard to environmental issues by the American economist Kenneth Boulding (1966). Later, in his report to the European Commission *The Potential for Substituting Manpower for Energy*, the architect and industrial analyst Walter Stahel investigated the potential positive impact of an economy organized in loops on employment, economic competitiveness, resource availability and waste reduction (Stahel, 1981). According to him, the circular economy is a model aimed to replace the ‘cradle to grave’ model of linear economy in a ‘cradle to cradle’ one. Then, Robert Frosch and Nicholas Gallopoulos, in their significant article *Strategies for Manufacturing* (1989), developed the concept of industrial ecosystems, on which is grounded the term ‘industrial ecology’. According to the industrial ecology, the waste produced by one company would be used as resources by another, in an analogue system of biological ecosystems. Eventually, in the new millennium, the model of an economy based on loops has been reintroduced by Bill McDonough and Michael Braungart in their book *Cradle to Cradle: Remaking the Way We Make Things* (2002). In this work, the authors call for a radical change in the industrial system with the aim of achieving a ‘delightfully diverse, safe, healthy, and just world, with clean air, water, soil and power – economically, equitably, ecologically and elegantly enjoyed’ (McDonough and Braungart, 2002).

In the same domain of the abovementioned collection of theoretical literature, at the beginning, the model of the circular economy have gained high consideration in China. China is a great emerging economy that nowadays is facing with problems concerning high urbanization and industrialization rates, as well as resources supply and environmental pollution. At the institutional level, China has been the forerunner of the use of the circular economy in the environmental policies. China is the first country that has adopted the new model as the foundation of its economic development by including it in both the 11th and the 12th ‘Five Year Plan’. The model of the circular economy was presented for the first time in China by the scientific community. In 2002, the model was formally accepted from the Chinese government as a new development strategy aimed to reduce the unbalance between China’s fast economic growth and the scarcity of raw materials and energy (Yuan et al., 2006). Thereby, a literature aimed to illustrate principles and goals in this field has been prospering in this country during the last ten years (Wang, 2005; Yuan et al., 2006; Zhijun and Nailing, 2007; Geng et al., 2009; Park et al., 2010; Mathews and Tan, 2011; Qiao and Qiao, 2013). As the diffusion of the circular economy increased, it has been gradually acknowledged as a feasible economic and environmental development strategy (Geng et al., 2009). Along the lines of the Chinese development strategy, the European Commission adopted the Communication *Towards a Circular Economy: a zero waste program for Europe* (EU, 2014) to establish a common and coherent EU framework to promote the circular economy. In general, the program was aimed to: i. extend the lifetime of products; ii. create recyclable materials markets; iii. reduce the use of non recyclable materials; iv. promote eco-design in order to facilitate maintenance, upgrade and remanufacture of products; v. stimulate the reduction and the separate collection of waste by consumers; and vi. reduce greenhouse gases emissions and environmental impact. In particular the program called for: i. by 2025, the increase of paper packaging waste recycling/re-use to 90%, the elimination of landfill for recyclable waste in not hazardous waste landfills in order to achieve a maximum landfill rate of 25%, and the reduction of food waste generation by 30%; and ii. by 2030, the increase of recycling/re-use of municipal waste to 70% and the increase of packaging waste recycling/re-use to 60% for plastics, to 80% for wood and to 90% for glass, aluminum and ferrous materials. However, this program was never put into practice and it was abrogated, while waiting a more ambitious program. Thereby, the new action plan has been proposed in December 2015, through the Communication *Closing the loop - An EU action plan for the Circular Economy* (EU, 2015). Among other goals, this revised proposal include: i. by 2030, a target for recycling 65% of municipal waste and 75% of packaging waste, as well as the reducing landfill to maximum of 10% of all waste; ii. Promotion of economic instruments to reduce landfilling and support recovery and recycling schemes; and iii. Real actions to promote re-use and encourage industrial symbiosis, turning one industry's by-product into another industry's raw material. Even though the new package was expected to be more ambitious than the previous one, lower targets have been set with regard to both municipal and packaging waste reduction. However, according to the EU Commission First Vice-President Frans Timmermans, the new package is more realistic (press communication[13]). Furthermore, the EU Commission President Jean-Claude Juncker claims that the ambition of the new package lies in its greater consideration of the whole process of closing the loops, whereas the previous one was concentrated much more on waste (press communication[14]). Along this line, even though the policies concerning the circular economy are rather recent, its concept and principles have already been implemented by some companies, organizations and institutions. To illustrate, some example is reported in Table 4.

Even though the term ‘circular economy’ has been linked with a set of meanings by different authors, it is always associated with the concept of cyclical closed-loop system (Murray et al., 2015). ‘Circular economy’ is a generic expression to define an economy that is restorative by intention and planning, and in which there are two types

[13] http://www.euractiv.com/sections/sustainable-dev/timmermans-defends-ambition-new-circular-economy-package-320049

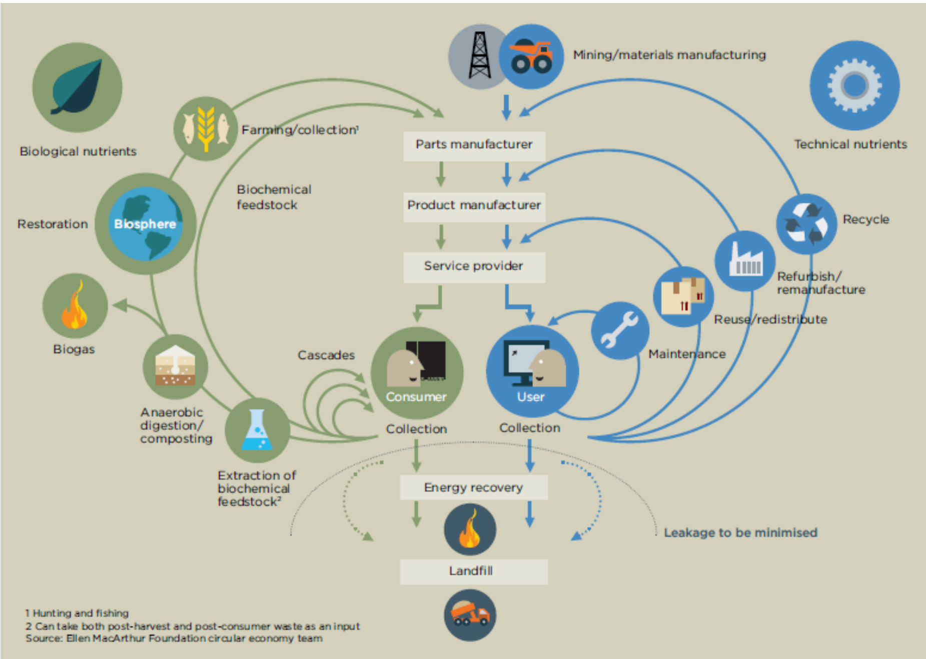
[14] *Ibidem*

Table 4. Examples of organizations that are already implementing the circular economy.

Category	*Name*	*Activity*
Non-profit organization	Ellen MacArthur Foundation	The *Ellen MacArthur Foundation* is a registered charity whose mission is to accelerate the transition to the circular economy. The *Ellen MacArthur Foundation* works with business, government and academia to build a framework for an economy that is restorative and regenerative by design.
Cooperative	Circle Economy	*Circle Economy* is a cooperative It works together with its members and partners on projects on a company, sector or regional level that accelerate the transition towards the circular economy.
Certification centre	C2C Products Innovation Institute	The *C2C Products Innovation Institute* is the official certification organization of cradle to cradle products.
Research and development centre	The LCA Centre	*The LCA Centre* is a R&D Centre of *Pacombi Group*. The *Pacombi Group* is a group of wholesale and distribution companies working in the field of packaging and disposables. *The LCA Centre* provides the group with information about the sustainability of their products and promotes the re-cycling and up-cycling of packaging.
Pension fund	PGGM	*PGGM* is a cooperative pension fund service provider. Institutional clients are offered asset management, pension fund management, policy advice and management support. It is trying to incorporate circularity in its sustainability policy.
Consultancy	Turntoo	*Turntoo* facilitates the transition of enterprises to the circular economy. It (re)design business models, organizational processes, financing structures, contract types, services or products. It focuses on performances rather than ownership.
Company	Desso	*Desso* is the early adopter and pioneer of cradle to cradle in its field. *Desso* produces carpets designed to be disassembled after the end of their life and the materials reused or recycled.
Company	Michelin	*Michelin* is the forerunner of the concept of leasing tyres and pay-per-kilometre programs. By maintaining control of the tyres during their usage period, Michelin can collect them after the leases, extend their technical life and reintegrate them into the material cycle at their end of life.
Company	Renault	*Renault* purchase used components of its vehicles from end-of-life disassemblers and furnish these to its distribution network.
Company	Ricoh	*Ricoh* is a provider of office equipment and IT services. *Ricoh* introduced a green program among its office solutions: copiers and printers return to the company after the leases, then they are refurbished and re-enter the market.
Company	Worn Again	*Worn Again* is a textile company. It has recently developed the first chemical recycling process to isolate polyester from cotton. This process is aimed to reuse polyester for the production of clothes.

of materials: biological nutrients and technical nutrients (Ellen MacArthur Foundation, 2012). Biological nutrients are designed to reenter the biosphere, while technical nutrients are designed to circulate without reenter the biosphere (Figure 7). Biological nutrients are organic and can be returned to the soil for becoming food for the ecosystem. They may be used in predefined ‘cascades’, where the quality deteriorates from one application to the next but, both along the way and at the end, the material can be fully returned to the biological cycle, with no harm to human health and the environment. Technical nutrients can include only materials that don’t have a negative impact on the environment. According to this model, the design of technical nutrients should refer to biological metabolism in order to develop a real ‘technical metabolism’.

Figure 7. Framework of the circular economy.



Source: adapted from Ellen MacArthur Foundation, 2012

The framework of the circular economy is based on the so-called ‘3R’ principles, namely ‘reduce, reuse, and recycle’ (Qiao and Qiao, 2013). ‘Reduce’ principle is aimed to reduce materials and energy that enter the processes of production and consumption; ‘reuse’ principle is referred to the extension of the life span of products; ‘recycle’ principle addresses the reduction of waste and its transformation in new resources. Then, the circular economy entails a complete reorganization of production systems which may be inferred from its main principle, namely ‘waste = food’. This principle strengthens the 3R by giving them a new meaning, different from the one they have in the linear economy. In the linear economy, in the best possible scenario, when waste doesn’t end up in landfills, it is recycled through ‘down-cycling’ processes, losing most of its intrinsic value (McDonough and Braungart, 2002). In this way, production chains are endless trapped in the same pattern. On the contrary, the circular economy is a model in which all steps of value chains are planned in order to make ‘someone’s waste the resource of someone else’ (Borrello et al., 2016). Thereby, the concept of ‘waste’ is abandoned, and products, according to the laws of regenerative design and of industrial ecology, are designed for cycles of disassembly and reuse with the aim of creating networks of industrial symbiosis among enterprises (Qiao and Qiao, 2013).

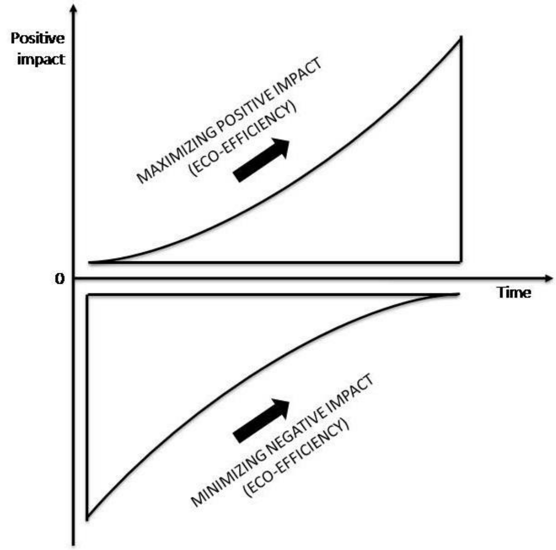
Other four principles related to specificities of the circular economy are defined as ‘powers’ (Ellen MacArthur Foundation, 2012, 2014): i. the ‘power of the inner circle’ refers to the fact that the shorter the circle the more value (in terms of energy, man and machine hours, and complexity) stays inside the product; ii. The ‘power of circling longer’ refers to de-incentivizing planned obsolescence and to a situation in which products are repaired, maintained, refurbished and resold in order to maintain and extend their value; iii. The ‘power of cascaded use’ refers to diversifying reuse across the value chain by extracting different products and materials through consecutive steps of different enterprises; and iv. The ‘power of pure circles’ consists in the value of creating loops of uncontaminated materials able to circulate longer

and more productively.
A universally acknowledged theoretical framework of the circular economy does not exist and a focus on social issues is still lacking among its many definitions (Murray et al., 2015). Thereby, some formalized principles suited for the circular economy may be inherited from Cradle to Cradle design (C2C design) (McDonough and Braungart, 2002). Circular economy and C2C design are strictly connected. Circular economy is needed to organize the innovations, to market new or renewed products, as well as organize the recycle stage. On the other hand C2C product design is needed to give insights into the environmental performance of materials, products, processes and systems, as well as into established and emerging technologies. Nevertheless, C2C can be used as a reference for gaining more insights about the circular economy. According to C2C, products are of two different types, namely consumption products and service products. Consumption products are made out of biological nutrients that can safely be consumed or worn off, and, if anything is left over, can safely return to the natural environment. Service products are made out of technical nutrients that should be returned to the technical cycle, where they will be used to follow consecutive cycles of production. According to the C2C design, products, instead of being conventionally sold to costumers, may be offered as a service. The product is taken by the customer who pay for the time or usage of it, for either a short or long contract period. In this model, a product that is used by the customer, formally or in effect, is owned by the manufacturer. The manufacturer maintains ownership of valuable material assets for continual reuse while the customer receives the service of the product without assuming its material liability. Service product represent the perspective of a cultural change conceptually connected to the revolution of the circular economy.
This change should remove the mechanisms of planning, positive feedback and perpetuation of the linear economy, namely the planned and the perceived obsolescence. This is implicit in a new framework that entails cooperation among elements of the value chain and the

celebration of products, no longer as properties, but as objects provided with function and usage. In this way, the idea of individuals being mere 'consumers' is replaced with the one of 'users' that are assumed to engage a cooperation with producers and/or retailers for the recycling of materials. To illustrate, individuals should return products to service providers, or to product manufacturers or to parts manufacturers (Figure 7). Then, the product may be repaired, redistributed to another user, remanufactured, or recycled into its components (Ellen MacArthur Foundation, 2012). Furthermore, the strategy of planning the life cycle of products at the post-consumer stage would help to accomplish the criterion of 'extended producer responsibility'. This criterion extends the responsibility of producers after products are discarded and become waste (Fishbein et al., 2000). By shifting this responsibility from governments to enterprises, producers are encouraged to implement closed-loop patterns of material use. Doing this, producers are incentivized also from becoming the owner of their materials and from the consequent lower subjection to the price increase and volatility of raw materials.

Circular economy can assimilate from C2C design also the concept of 'eco-effectiveness'. Eco-effectiveness represents a shift from the idea of eco-efficiency used by conventional sustainability. Eco-efficiency is based on reducing damages of human activities on the environment in order to minimize their negative impact. Even though the approach of intervening on an impacting economy by diminishing extraction of raw materials, pollution and waste is rationale, the circular economy tries to strenghten this concept by means of the idea of eco-effectiveness (Figure 8). Eco-effectiveness is aimed to maximize the positive impact of human activities by creating a 'supportive relationship with ecological systems and future economic growth' (Braungart et al., 2007). According to eco-effectiveness, materials should preserve their status of resources and 'accumulate intelligence over time'. Thereby, the down-cycling of waste is replaced by its 'up-cycling', in which by-products, waste materials, useless and/or unwanted products are transformed into new materials or products of better quality.

Figure 8. Eco-efficiency vs eco-effectiveness .



Source: elaboration from the text

Companies that are committed to the circular economy and that are able prove the fulfillment of certain criteria, can get a certification from the *C2C Products Innovation Institute*[15]. Unfortunately, food products are excluded from the list of products that can get a certification. Nevertheless, the potential of materials generated during agri-food supply chain for being used within the framework of the circular economy is high. As mentioned above, the circular economy considers two types of nutrient, namely biological nutrients and technical nutrients. The former, if not toxic, can be returned to the biosphere. Short-lived products and consumables belong to the category of biological nutrients and represent about a third of European manufacturing sector (Ellen MacArthur Foundation, 2012). Among these, food and other agricultural products may have a lifespan of only a few months, or even days. As a consequence, in the

[15] http://www.c2ccertified.org/

circular economy, this kind of products should have a restorative purpose and be reintegrated in the biological metabolism of Earth.

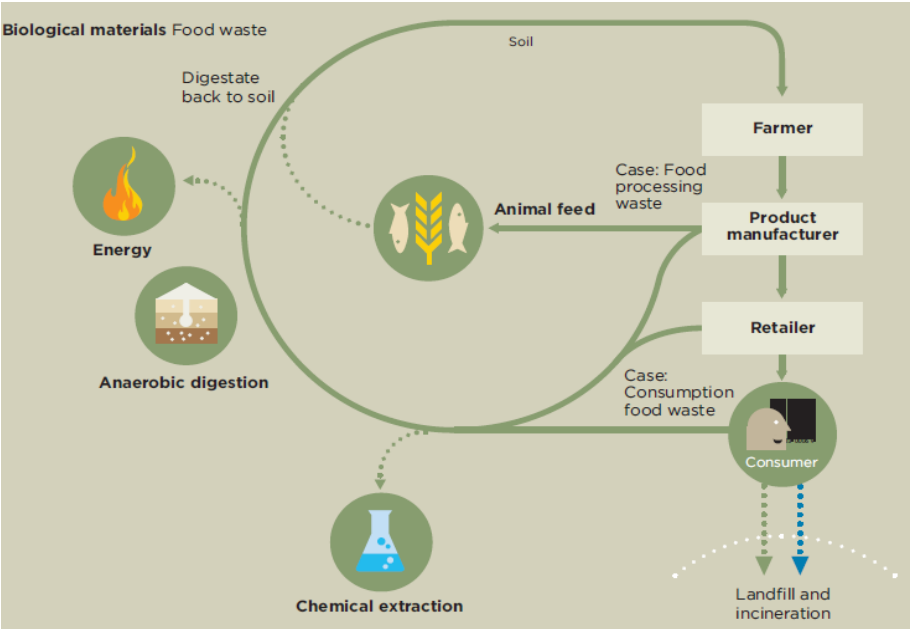
With regard to the aims of this thesis, food losses and waste are an important segment in the list of consumables category, as well as they are significant contributors to the present waste production. Furthermore, they have considerable potential in being returned to the biosphere to rebuilt natural capital after energy and specific nutrients have been extracted on the reverse loop. The purpose of the circular economy in the agri-food sector is to avoid wasting of biological materials and to extract the maximum value from agricultural products by up-cycling their residues as inputs of new production processes. Different processes are available for implementing the circular economy in the agri-food sector (Figure 9). To illustrate, food losses and waste may be used as alternative feed sources for livestock. The recycling company *Viridiun LLC*, has launched a massive food waste collection, in order to recycle fruit, vegetable and bakery food waste from hundreds of Wal-Mart stores located in the Southeast, Midwest and Northeast of the US[16]. Nutritional analysis have shown the feed resulting from the processing of this waste to be very palatable and energy concentrated. The value of this novel feed byproduct is USD 50-70 per metric ton and livestock breeders are now making profit by using it.

Agri-food reverse loops have the typical characteristic of producing soil nutrients to restore the land. For instance, compost is a useful material for returning biological nutrients to the soil. Compost is produced through composting, the biological process during which organisms like bacteria, fungi, insects and earthworms decompose organic matter into a soil-like material. If 100% of food waste resulting from consumption and 50% of other types of food waste was given back to the soil, it could produce 5 million metric tons of nitrogen, phosphates and potassium (N, P, K), the most used

[16] http://www.caes.uga.edu/Applications/ImpactStatements/index.cfm?referenceInterface=IMPACT_STATEMENT&subInterface=detail_main&PK_ID=4359

fertilizers. This would imply the substitution of 4% of the current consumption of these three minerals, as well as it would mitigate the dependence on imports from foreign countries (Ellen MacArthur Foundation, 2013).

Figure 9. Food and beverage – retail, household, and production.



Source: adapted from Ellen MacArthur Foundation, 2013

Furthermore, food waste can be used for producing energy in different ways. Anaerobic digestion and incineration are the most applied methods for generating energy from biological residues. Anaerobic digestion is a process in which microorganisms decompose organic materials in a non-oxygenated environment and create two different products: biogas and digestate. The former is composed by methane and CO_2, and can be used as fuel. The latter is a liquid or solid residue, and can be used as fertilizer. Incineration is a process in which waste is converted by means of combustion into ash, gas and heat, that are useful to generate electric power. These technologies are already spread. To illustrate, in developing countries anaerobic digestion is a common way to produce fuel from food waste and animal manure (El-Mashad and Zhang, 2010; Bond and Templeton, 2011). Moreover, worldwide capacity to produce biomass generated electricity, is estimated to be around 72 GW (Ellen MacArthur Foundation, 2013, data from 2011).

However, in order to fully capitalize on food losses and waste, the maximum of its value should be extracted before it is used to produce energy or fertilizers. The most advanced form of valorization is the ‘bio-refinery’. In bio-refineries, the principle of ‘cascading’ is applied. Here, biological materials are transformed through enzymes and bacteria into proteins and sugars, and then in plastics, medicines, and fuels. According to Clark et al. (2006), the implementation of chemical technologies on biological waste can pave the way to the birth of new sustainable chemical and materials industries for the future.

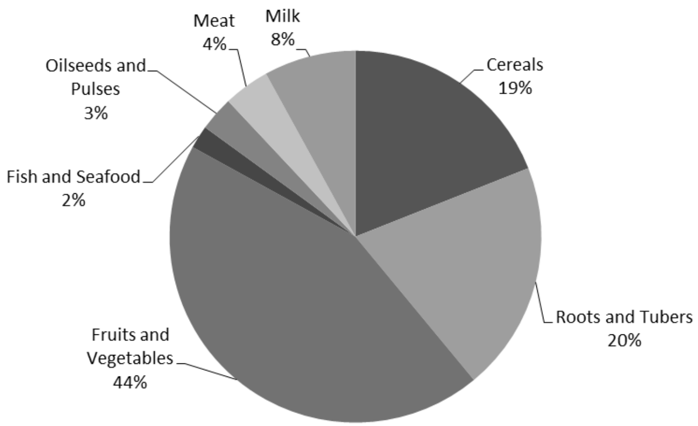
The possible benefits of the transition to a circular economy in the agri-food sector were investigated from the Ellen MacArthur Foundation (2012), the main non-profit organization that has the aim of accelerating the transition to the circular economy. More specifically, the Ellen MacArthur Foundation assessed, the whole consumption stage of the agri-food value chain and only one product for the food processing stage. At the consumption stage, the assessment considered the waste produced by retailers, restaurants and households. In the UK, where the headquarters of the foundation is situated, the creation of reverse cycles was estimated to generate profits of USD 172 per metric ton, so generating potential economic opportunities for institutions and business ventures. At the food processing stage, losses in the form of by-products were investigated considering the industry of beer. Brewer’s spent grains could be used as feed for livestock and fish, as well as nourishment for anaerobic digestion. In the circular model, these alternative uses are worth USD 1.91 per hectoliter of beer produced.

Even if the circular economy has a great potential for be implemented into the agri-food sector, the path towards the transition is still long. The transition to the circular economy cannot be conceived as a process limited to the scattered venture of isolated companies or organizations. According to Zhijun and Nailing (2007), the circular economy has many aspects and should be phased in moving from micro to macro level. These aspects should involve, step by step, enterprises, industrial areas, cities, and regions. Companies should develop ecological cycles of materials and energy embedded in their industrial framework, maximize resources use and minimize pollution. In industrial areas, materials and energy flows among facilities should be created by implementing the 'waste = food' principle and forming an interdependent ecological industrial system. In cities and regions, the circular economy should be achieved by limiting energy use and waste discharge, reducing pollution and changing consumption system. All these steps need the acquisition of more insights in many areas. More specifically, the understanding of the challenges that the circular economy will be facing for replacing the linear model are crucial. This thesis is aimed to give a contribution in this domain, focusing in particular on the transition to the circular economy in the agri-food sector. This contribution will be given by pursuing a twofold goal: i. outline the challenges for the implementation of the circular economy into agri-food supply chains; and ii. analyze in depth the challenge of the new model that is related to consumers.

1.3 Food losses and waste: impacts of the linear economy in the agri-food sector

The agri-food sector, on which we focus our attention, is an example of linear model where materials wastages are observed along the value chain. Parfitt et al. (2010) make a list of three definitions stepping up from a narrow towards a broad characterization of food waste: i. wholesome edible material intended for human consumption, arising at any point in the food supply chain that is instead discarded, lost, degraded or consumed by pests (FAO, 1981); ii. as (i), but including edible material that is intentionally fed to animals or is a by-product of food processing diverted away from the human food (Stuart, 2009); iii. As definitions (i) and (ii) but including over-nutrition, namely the gap between the energy value of consumed food per capita and the energy value of food needed per capita (Smil, 2004). If edible parts of food produced for human consumption are reported, these wastage entail the loss of about one third of the food produced worldwide for human consumption. This quantity, approximately 1.3 billion metric tons per year distributed among many food commodities (Figure 10), is represented with a significantly greater amount in developed countries (FAO, 2011). Waste is produced at the farm level, in the processing industry, during distribution and at the household level. This amount of agri-food waste creates a parallel industry to the production industry and generates a long list of negative externalities. Huge costs in terms of resources consumption and of greenhouse gases produced in vain during production and landfilling are observed. To illustrate, UK could save USD 1.1 billion and 7.4 million metric tons of greenhouse gases emissions per year, by avoiding the landfill disposal of organic food waste (Ellen MacArthur Foundation, 2012).

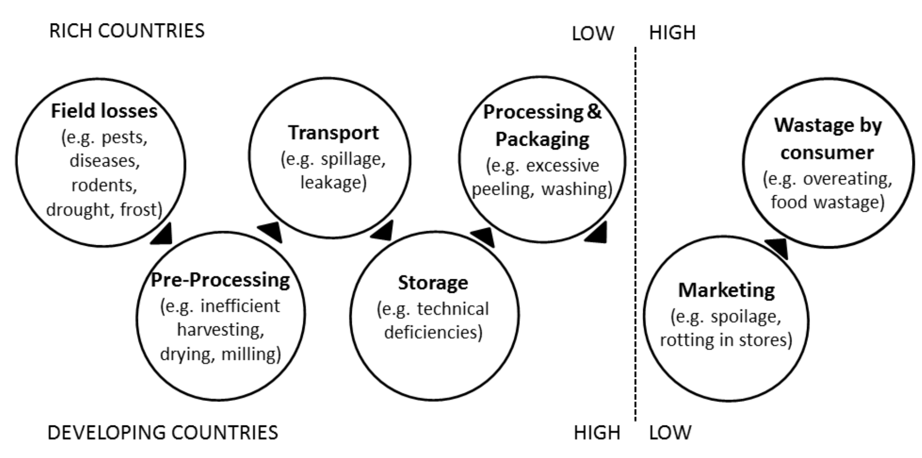
Figure 10. Share of global food losses and waste by commodities, 2009.



Source: data from Lipinski et al., 2013

Waste is not produced always for the same reason. Wastages differ depending on the step of the agri-food supply chain that is considered, on the type of product, as well as on the place where the waste is produced. More specifically, wastages in the agri-food sector are classified in ‘food losses’ and ‘food waste’ (Parfitt et al., 2010). Food losses are wastages that occur during the first part of the value chain: field losses, pre-processing, transport, storage processing and packaging; food waste is referred to later stages of value chains: marketing and consumption. In low income nations, food losses represent the majority of wastages because they are caused, to a greater extent, by technical and infrastructural inefficiencies occurring at the beginning of the production chain. On the contrary, in medium and high income nations, the majority of wastages is represented by food waste (Figure 11). This is caused by the behavior of consumers and by the scarce coordination among the actors of value chains. Furthermore, in western countries, abundance just make people able to afford to waste food (FAO, 2011).

Figure 11. Extent of food losses and wastages by level of development.



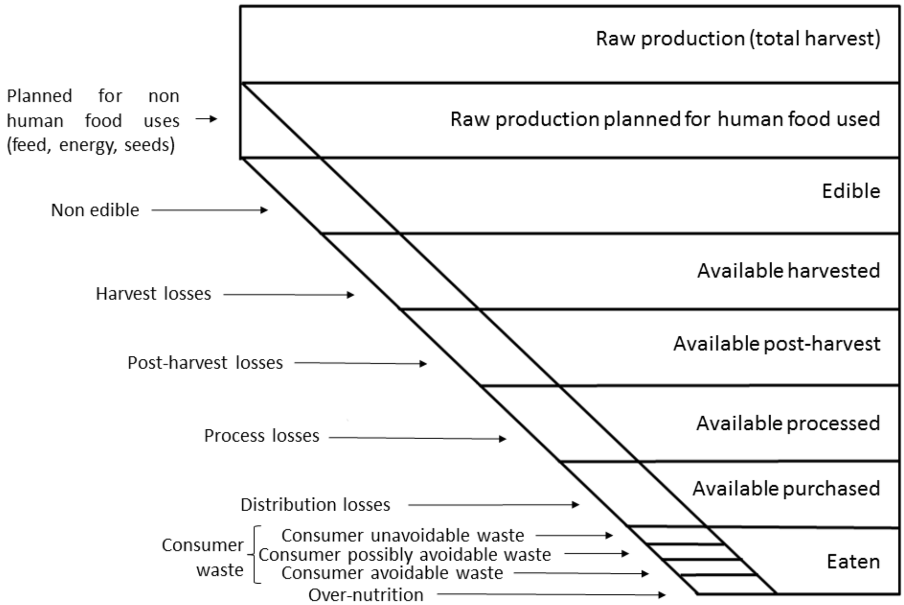
Source: elaboration from the text

In developing countries, agri-food losses are due to a great extent to the low scale of farming. Moreover, in these countries the agri-food sector is characterized by low efficiency and by low technical, financial and managerial skills of farmers. At the field level, part of the crops are lost because of biotic or abiotic agents and to the backwardness of agronomic practices. Underdeveloped techniques concerning soil preparation, planting and cultivation result in lower crop resistance to stress and lower farm's yield, as well as being the first cause for agri-food losses. Furthermore, premature harvesting due to food scarcity can cause the loss of nutritional and economic value of products and, in some cases, can make them not suitable for consumption (FAO, 2011). At the post-harvest level, in warm regions, food losses are incremented by the combination of climate conditions and infrastructural deficiencies. Developing countries are often located in world areas characterized by warm climate that accelerates the decaying rate of agricultural products. This is critical during the post-harvest phase because of the scarcity and inefficiency of transport, storage, refrigeration and processing facilities (Stuart, 2009).

In industrialized countries, agricultural production can exceed the demand of food in order to prevent damaging consequences of poor weather or crop pests (FAO, 2011), often determining the wastage of the surplus. Moreover, aesthetic standards of supermarkets often prevent that part of the yields pass the post-processing 'exam' or even that it could leave farms (Stuart, 2009). Similarly, food products not suitable for consumption because of safety reasons, toxins, polluted water or unsafe use of pesticides, are inevitably wasted. Then, once arrived to supermarkets, products face the dynamics of sale. Retailers order many and diversified products because of economic convenience and costumers needs. Therefore, shelves stuffed of food increase the probability that many products, ignored by consumers, surpass their expiring date (Ellen MacArthur Foundation, 2012). Finally, at the household level, a considerable amount of food is even not cooked or eaten. A research carried out in Great Britain classifies household food and drink waste in three categories, by how avoidable this waste is: i. avoidable is food and drink thrown away that was, at some point prior to disposal, edible (e.g. slice of bread, apples, meat); ii. possibly avoidable is food and drink that some people eat and others do not (e.g. bread crusts), or that can be eaten when a food is prepared in one way but not in another (e.g. potato skins); and ii. unavoidable is the waste arising from food or drink preparation that is not, and has not been, edible under normal circumstances (e.g. meat bones, egg shells, pineapple skin, tea bags). A dramatic example of household food waste production is observed in the US, where the average family wastes half the food purchased, for a value of USD 164 billion (FAO, 2011).

A scheme aimed to summarize various perspectives concerning what is food waste is shown in Figure 12.

Figure 12. Food losses and waste.



Source: adapted from HLPE, 2014; including information from Smil, 2004, WRAP, 2008 and Stuart, 2009

With regard to the sustainability of food losses and waste, an huge amount of natural resources is used in vain for producing food that will not be consumed. Sustainable development has been traditionally described in terms of three dimensions, domains or pillars (UN, 2014). These three dimensions are ‘environmental, economic and social’ or ‘ecology, economy and equity’. The impact of food losses and waste can be evaluated with regard to the three domains of sustainability.

Supply chains of food have an environmental impact like any other supply chain. The life cycle of food products has an impact in terms of energy consumption, resource exploitation and greenhouse gas emissions. These impacts are generated during production, processing, transportation, marketing, consumption and disposal. As long as part of the outcome of food supply chains will go lost, part of their negative externalities will be generated in vain. An assessment of the environmental impact of food waste was carried out from the Food and Agriculture Organization (FAO, 2013). For this purpose, the report considers four different model components: i. carbon footprint; ii. water footprint; iii. land occupation/degradation impact; and iv. potential biodiversity impact. Other authors (Buchner et al., 2012) prefer ecological footprint (Wackernagel and Rees, 1998) to summarize, other than carbon and water footprint, other environmental impacts of agri-food waste. Even though an universally accepted definition is still debated (Wright et al., 2011), the carbon footprint of a product is commonly considered the total amount of greenhouse gases (GHGs) emitted during its life cycle, expressed in kilograms of CO_2 equivalents. A CO_2 equivalent is a metric measure used to compare the emissions from various greenhouse gases based upon their global warming potential[17]. For the calculation is used the Life Cycle Assesment (LCA). LCA is a methodology suitable for the evaluation of the overall environmental impact of a product, concerning all phases related to it (Freda et al., 2015). Without taking

[17] http://www3.epa.gov/climatechange/glossary.html

into account GHG emissions generated from land use change, the carbon footprint of food waste is estimated to 3.3 Gtonnes of CO_2 equivalent. According to the FAO report, this amount make food wastage 'the third top emitter after USA and China'. The water footprint is defined from the Water Footprint Network as the amount of freshwater used directly or indirectly to produce it[18]. Since the greatest impact of food production on water resources is reported at the agricultural level (Hoekstra and Mekonnen, 2012), other phases of food supply chains are excluded from the calculation of water footprint. For the assessment, irrigation water from ground and surfaces ('blue water') is considered. The water footprint of food waste amount to around 250 km^3, 'which is equivalent to the annual water discharge of the Volga river, or three times the volume of lake Geneva'. Land use is 'the modification and/or management of land for agriculture, settlements, forestry and other uses including those that exclude humans from land, as in the designation of nature reserves for conservation'[19]. Food that is produced and not eaten vainly occupies almost 1.4 billion hectares of land, that is the 30% of the world's agricultural land surface. This amount regards the surface of land needed to produce this food. The environmental impact of land use is related to many other issues regarding land use change and land degradation. Nevertheless, the indicator used for the calculation includes only partially this kind of impacts for their higher uncertainty and because they are less easy to understand. As regard as biodiversity depletion, the FAO report limits its focus to a qualitative review related to agricultural productions in general. This review underlines scientific evidences about the impacts of the different food commodities on biodiversity. To illustrate, the impact of mono-cropping in terms of agricultural expansion into wildlife areas is considered. Ecological footprint is calculated using as measure the global hectare, a biologically productive hectare with world average

[18] http://waterfootprint.org/en/water-footprint/glossary/#WF
[19] http://www.eoearth.org/view/article/154142/

biological productivity for a given year[20]. Data are available for two kind of products (fruit/vegetables and meat) and for one country (Italy) (Buchner et al., 2012). The ecological footprint of 1kg of fruit or vegetable waste amounts to 3.7 global m^2, whereas the ecological footprint of 1kg of meat waste amounts to 38 global m^2. Even, if these data are confined to the case of Italy, they are meaningful to underline the extremely higher impact of meat waste in comparison to other kind of food waste.

Two methods can be used in order to assess the economic impact of food waste that are the production cost and the market price of goods (Buchner et al., 2012). According to the first method, that is based on classic economics, the value of an item or a service is proportional to the value of the resources needed to produce it[21]. Production cost combine raw material and labor. To illustrate, in the case of food, this criterion implies the inclusion within the estimation of costs of: the purchase of seeds, fertilizers and other technical resources; amortization charges, maintenance and insurance; machines and warehouses; irrigation systems; energy; taxes; remuneration of labor. The second method is grounded on the neoclassical school of economics. According to this method, the value of a good is implicit in its market price. In economics, the market price is the economic price for which a good or service is offered in the marketplace[22]. Thereby, in the case of food products, economic value has to be identified in the price at the retailing. Since food waste affect also the environment and the society, Buchner et al. (2012) suggest that its impact should be calculated taking into account welfare economics. Welfare economics considers the social utility of a good by including, other than measures of economic efficiency, also social well-being and equity[23]. Therefore, in the calculation of the value of a certain food, an estimation of the price society is willing to pay for the

[20] http://www.footprintnetwork.org/en/index.php/GFN/page/glossary/
[21] http://www.investopedia.com/terms/p/production-cost.asp?layout=infini
[22] http://www.investopedia.com/terms/m/market-price.asp?layout=infini
[23] http://www.investopedia.com/terms/w/welfare_economics.asp?layout=infini

environmental impact due to its production is included. Finally, the opportunity cost of the agricultural area used to produce the food wasted can be added to this calculation. According to these criteria, Segré and Falasconi (2011) estimated the economic value of the food wasted in Italy. This value amounts to € 8 billion and, if we move from production cost to market value, it increases up to € 10 billion. If we consider also the value of negative externalities related to the environmental impact and the opportunity cost of the land, this value reaches € 30 billion. In the UK, a study was conducted with regard to the food waste produced at an household level (WRAP, 2008). The value of good food paid but not eaten in the UK amounts to £10.2 billion, that is £420 of avoidable food for the average family each year. The value of food thrown away whole and unopened surpasses £2.3 billion a year, whereas food still in date that is wasted is worth at least £950 million per year. In the US, where the calculation is based on the sole market value, the avoidable food waste has a total retail value of USD 198 billion that are mostly allocated at the consumption stage. The consumer waste alone is worth USD 124 billion, that is about 63% of the overall retail value of wasted food. The per-capita retail value of total avoidable waste is USD 644 per year. The avoidable consumer waste part of this amount to about USD 1600 per year for a family of four (Venkat, 2012).

There is not a standard indicator for measuring the social impact of agri-food waste. However, this impact can be debated theoretically with reference to concepts like food security and starvation. Food security refers to the possibility to provide constantly water and food to fulfill the energetic needs of human organisms. The 1996 World Food Summit (FAO, 1996) adopted the current and internationally accepted definition of food security: 'Food security, at the individual, household, national, regional and global levels (is achieved) when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life'. Bickel et al. (2000) propose three definitions for 'food security', 'food insecurity' and ‘hunger’: i. ‘(Food security is the) access by all people at all times to enough food for an active, healthy life. Food security includes at a minimum: (1) the ready availability of nutritionally adequate and safe foods, and (2) an assured ability to acquire acceptable foods in socially acceptable ways (e.g. without resorting to emergency food supplies, scavenging, stealing, or other coping strategies)’; ii. ‘(Food insecurity is the) limited or uncertain availability of nutritionally adequate and safe foods or limited or uncertain ability to acquire acceptable foods in socially acceptable ways’; and iii. ‘(Hunger is) the uneasy or painful sensation caused by a lack of food. The recurrent and involuntary lack of access to food. Hunger may produce malnutrition over time (…). Hunger is a potential, although not necessary, consequence of food insecurity’. At the opposite extreme of this range of conditions related to food availability is ‘starvation’. Starvation, the extreme form of malnutrition, is ‘the result of a severe or total lack of nutrients needed for the maintenance of life’[24] which can cause permanent organ damage and death. Although enough food is already being produced to feed the world’s population (FAO, 2002), hunger, malnutrition and starvation still exist in many parts of the word. The causes related to this matter of fact concern a web of political and environmental problems that will not be debated in this work. Though agri-food waste is one of these problems, real origins of food insecurity and of its extreme consequences are very multifaceted and cannot be relegated to food wastages. The reduction of agri-food waste in a developing country or the importation of food surplus from developed ones would not necessarily turn out into an increase of food security. However, agri-food waste can be used as a synecdoche in the field of inefficiencies of agri-food supply chains. It is an iconic loop of this sector able to suggest the inability of food systems to fulfil nutritional human needs. Agri-food waste attests the existence of an imbalance among countries in the availability and accessibility to food. This is demonstrated by the relative importance of ‘fateful’ food

[24] http://medical-dictionary.thefreedictionary.com/starvation

losses in food-insecure countries, versus ‘behavioural’ food waste in food-secure countries (HLPE, 2014). Furthermore, if one wants to look at the direct and recognizable consequences of the production of agri-food waste on food security, three main issues come out (HLPE, 2014): i. a decrease of global and local availability of food; ii. raising prices and economic losses that lead consumers, from one side, and actors along the value chain, from the other side, to a reduced access to food resources; and iii. long-lasting consequences on future supplies of food related to the inefficient and unsustainable use of natural resources.

1.4 Materials and methods

The first paper presented in this work (chapter 2) is aimed to outline the future challenges of the circular economy in the agri-food sector. This paper is based on a purely conceptual approach. Starting from the stylized scheme of a real supply chain, we designed an hypothetical circular counterpart of this chain including additional actors and innovative technologies useful for closing every loop. The supply chain selected was the one of bread. We did not claim that this prototype would be the more efficient or effective for reaching the goal of minimizing food losses and waste produced during the supply chain selected. However, lacking any real analogous chain, we took advantage from our design in order to achieve our purposes. Scientific literature and legislations supported us to reason about strengths and weakness of the supply chain proposed. Once identified the main challenges, we transferred these challenges to the whole agri-food sector through a generalization process grounded on similarities among supply chains.

The second paper of the thesis (chapter 3) is an assessment of the consumers’ willingness to be actors of the circular economy. Also in this case, we designed an hypothetical food circular supply chain which implied the participation of consumers through the restitution of their organic food waste to retailers and the subscription of a program. The organic food waste would be used for the production of animal food products for which consumers could obtain discounts through the participation to the program. Our rationale excludes any assumption regarding the feasibility and the potential effectiveness of the process described. The survey was instead aimed to capture consumers' willingness to be actively involved in the circular economy. More specifically, we wanted to study this willingness when it comes to participate to a circular supply chain through the commitment to a program with retailers and through the compliance of specific tasks concerning the recycling of organic food waste. In this domain, we carried out a survey through a structured questionnaire submitted to a representative sample of Italian Households (1,270 interviewees). The questionnaire was submitted through GFK, a global company which performs market and consumer studies. A choice experiment was implemented in order to analyze attributes of a program of participation. Preferences and trade-offs, in monetary terms, among attributes were computed.

More detailed information about materials and methodologies used in this thesis are included in chapter 2 and chapter 3.

Chapter 2

THE SEVEN CHALLENGES FOR TRANSITIONING INTO A BIO-BASED CIRCULAR ECONOMY IN THE AGRI-FOOD SECTOR

Abstract: Closed-loop agri-food supply chains have a high potential to reduce environmental and economic costs resulting from food waste disposal. This paper illustrates an alternative to the traditional supply chain of bread based on the principles of a circular economy. Six circular interactions among seven actors (grain farmers, bread producers, retailers, compostable packaging manufacturers, insect breeders, livestock farmers, consumers) of the circular *filière* are created in order to achieve the goal of ‘zero waste’. In the model, two radical technological innovations are considered: insects used as animal feed and polylactic acid compostable packaging. The main challenges for the implementation of the new supply chain are identified. Finally, some recent patents related to bread sustainable production, investigated in the current paper, are considered. Recommendations are given to academics and practitioners interested in the bio-based circular economy model approach for transforming agri-food supply chains.

Publication information: Borrello M., A. Lombardi, S. Pascucci & L. Cembalo, 2016. The Seven Challenges for Transitioning into a Bio-based Circular Economy in the Agri-food Sector. Recent Patents on Food, Nutrition & Agriculture, 8(1), 39-47.

2.1 Introduction

According to the ecological footprint index (Wackernagel and Rees, 1998), to date mankind uses the equivalent of 1.3 planet Earths per year. This estimate represents the biologically productive area that would be necessary for the world's population to live sustainably, which is clearly far beyond the real availability we can count on. Consequently, since the publication of *The Limits to Growth* by the Club of Rome (Meadows et al., 1972), the supply of natural resources and the environmental impact of human activities have given cause for concern among the scientific community. On this issue, Diamond (2005) claims that modern industrial society is heading towards collapse and assumes the irrational exploitation of natural resources to be one of the reasons for this trend. On this subject, Qiao and Qiao (2013) summarize the characteristics of the modern economy as follows: high resource exploitation, high consumption, high waste production and low efficiency. This means that, in the market economy and in the so-called consumer society, too little attention is given to environmental impacts of economic activities.

By contrast, finding its basis in Georgesçu-Roegen's bioeconomy theory (Georgesçu-Roegen, 1971), the economy may be considered as a subfield of ecology (ecological economics). Ecological economics investigates reciprocal barriers between natural and production systems, focusing on long-term environmental sustainability. At the same time, according to the declarations of the *Brundtland Report* (WCED, 1987), sustainable development models have been the focal point of international environmental policies. According to such models, human activities should be compatible with the preservation of nature in order to achieve intra- and inter-generational ecological equity. Both ecological economics and sustainable development, deriving from a new awareness of the role of mankind in nature, aim to establish a different equilibrium between human activities and needs, and the environment.

Following this new sensitivity to environmental issues and the new theoretical approaches to the production-environment pairing, the idea of a renewal from the top of economic systems has started to spread. This idea finds its basis in the circular economy model. Since its first implementation in China, required to deal with the environmental problems of its emerging economy (Yuan et al., 2006), the circular economy has started to be considered a potential revolution in the history of economic development models. It takes its origin from a peculiar feature of the modern industrial system, which is the orderliness of the production pattern. In this system, materials are harvested or extracted. They are then used to produce goods to be sold to customers or consumers, who finally dispose of them after use. It is evident that in this pattern, called in the scientific literature 'take – make – dispose' (Ellen MacArthur Foundation, 2012) or 'resources – manufactured product – pollution emissions' (Qiao and Qiao, 2013), resources and processes follow only one linear direction along the value chain. It is a linear pattern and, as long as it persists, the current worldwide economy can be considered a linear economy. According to McDonough and Braungart (2002), this linearity implies that products are trapped in a 'cradle to grave' life cycle in which little or nothing reenters the value chain. Hence, production continuously needs raw materials to be extracted and, in the best possible scenario, when products do not end up in landfills, they are recycled through downcycling processes, losing most of their intrinsic value. In addition, the linear model influences the relationship between consumers and products. Except for domestic recycling, consumers have no responsibility towards the product and may be considered mere intermediaries between retailers and waste collection.

Circular economy aims to transform this linear pattern into a circular one, pursuing the creation of a 'cradle to cradle' production system (McDonough and Braungart, 2002): in order to reduce resource exploitation and waste production, the economy of the future should be based on reuse and recycling of materials. Furthermore, the circular economy entails a complete reorganization of production systems which may be inferred from its main principle. This principle strengthens the traditional concept of recycling because, instead of using waste to obtain lower value products, it assumes that all steps of the value chain are planned in order to make someone's waste the resource of someone else (Ellen MacArthur Foundation, 2012). Furthermore, the idea of individuals being mere 'consumers' is replaced with the 'users' that are assumed to engage a cooperation with producers and/or retailers for the recycling of materials.

In the framework of the circular economy, agri-food products would have a significant potential. Wastage is generated during each step of the agri-food supply chain, from production to consumption (Parfitt et al, 2010). Approximately one third of the food produced for human consumption (1.3 billion metric tons per year) is lost (FAO, 2011), with some authors estimating this amount to be as high as half of all food grown worldwide (Lundqvist et al., 2008). Food can thus be considered a major contributor to present waste production. This unreasonable wastage, in addition to generating obvious ethical questions regarding poverty and social justice, involves enormous environmental and economic costs due to disposal. The goal of the circular economy in the agri-food sector would be to prevent food waste in order to mitigate such costs. Biological materials move within ecosystems following a continuous flow of matter and energy. Circular agri-food supply chains can take advantage of these natural mechanisms within their structures. This could be achieved by creating networks of factories in which organic by-products, instead of being landfilled or directly returned to the soil, are used as inputs of new production. Food waste may be taken into account as an alternative feed source for livestock (Sugiura et al, 2009). It can be used to produce fertilisers (Ellen MacArthur Foundation, 2013) or to generate energy in different ways (Kiran et al., 2014). Agri-food residues can also be considered for biorefineries (Mirabella et al., 2014) where, through enzymes and bacteria, biological materials are transformed into proteins, sugars, plastics, medicines and fuel.

The circular economy approach would also help to accomplish priorities defined from the CAP (Common Agricultural Policy) for the period 2014-2020 (EU, 2013a). Circular economy would allow improving environmental performances of agri-food systems through the implementation of innovative business models. It would also add value to agricultural products by providing them of new attributes concerning their sustainable production. Even these attributes are related to CAP priorities. Circular economy would increase efficiency in food processing and would help to fulfil the purposes concerning bio-economy related to the reuse of by-product, waste and residues. Furthermore, the reuse of organic residues as fertilizers would contribute to soil restoration and to the prevention of soil erosion.

Although the potential economic and environmental benefits of a bio-based circular economy have already been assessed (Ellen MacArthur Foundation, 2012), the implementation of its principles in the organization of an agri-food supply chain still requires significant effort. Our contribution falls in this domain. Agri-food supply chains have to face several challenges. Reuse of materialsand the common practice of high resource productivity require a massive effort in terms of supply chain reorganisation. Though the circular economy constitutes a potential revolution in the history of economic development models, it means that the traditional linear model will have to bow out, giving way to the principles of the circular economy. Political, legal, economic, social and technological barriers will have to be tackled before the circular economy can be implemented. Some of these barriers are product- and process- specific. This contribution seeks to highlight the
major barriers to achieving a smooth transition into a biobased circular economy in the agri-food sector. Our approach is purely conceptual. To illustrate, starting from a description of a stylised real supply chain, we depict a counterpart circular version. This is followed by an attempt to underline the challenges (threats and weaknesses).

Among food products which have a major issue of wastage before and after distribution, bread gives cause for serious concern. For instance, in the UK, bakery waste accounts for 13.4% in quantity and 10.8% in cost of all food wasted (WRAP, 2008). The circular model we conceived has a high applicative potential in the system of bread production and consumption. The 'transformed' circular framework considers several material flows and allows waste production to be reduced to a minimum (bordering on zero waste), exploiting any residues for value creation.

The innovation of this paper, to the best of our knowledge, lies in its conceptualization of a circular model applied to agri-food supply chains. Its importance is strongly related to its usefulness. Companies intent on applying circular organization need to know what challenges they have to face. On the consumption side, a new way of thinking is crucial. In most cases going from the concept of 'ownership' to that of 'user-ship' is no trivial task. In this way we define a framework of guidelines for stakeholders intending to lend their contribution to the implementation of the circular economy in the agri-food sector.

2.2 Materials and methods

In order to design a new circular model for the supply chain of bread, we designed a potential network in which seven actors are involved: grain farmers, bread producers, retailers, compostable packaging manufacturers, insect breeders and livestock farmers (poultry, pigs, fish) and consumers. In this conceptual map two radical technological innovations are introduced: one in the packaging (a compostable type) and the other regarding livestock nutrition (insects as a source of protein for feed). Compostable packaging is made of biodegradable and toxin-free materials and can be added to other organic matter in the production of compost, a soil-like material suited to restoring cultivated soils. As for the second technological innovation, the interest in insects as a potential source of protein for livestock is steadily growing (FAO, 2013b). Many kinds of insects are part of the natural diet of farmed animals like chickens and fish (Gullan and Cranston, 2005). Along this line, business ventures in this sector are already extracting proteins from insects, selling them whole, or producing feed derived from insect processing. The core of the recycling system we conceived is the traditional linear chain of bread wrapped in its packaging: production of raw materials, production of bread and packaging, supply to retailers, sale to consumers and disposal (Figure 13).

Starting from the linear model, we imagined a number of actors and material flows to be embedded in it in order to create six circular interactions able to generate no leakages of matter. The circular system we conceived is depicted in Figure 14.

The first circle we considered is between grain farmers and bread producers. In this interaction the loop is closed with bread producers returning production residues to farmers. Farmers can then use these residues to make compost for agricultural soil.

Figure 13. Linear-based framework for the production, consumption and disposal of bread.

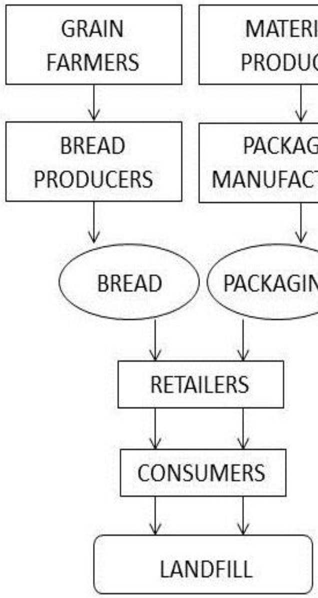
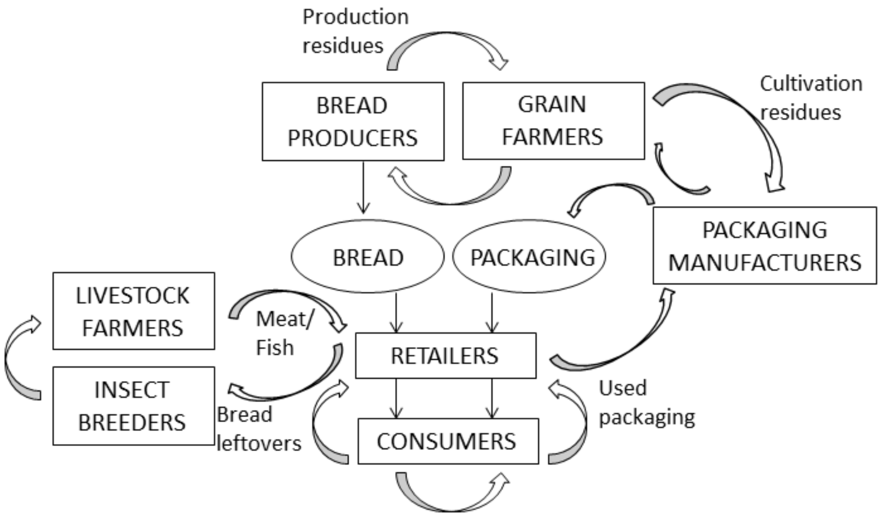


Figure 14. Circular-based framework for the production, consumption and reuse of bread.



The second circle we considered is between packaging manufacturers and retailers. As compostable packaging, we considered polylactic acid (PLA). PLA is produced by a controlled depolymerisation of the lactic acid monomer obtained from feedstock derived from renewable resources, like starch (Garlotta, 2001). Polylactic acid can be recycled to a monomer which, once purified, can be used to manufacture virgin PLA without a significant reduction in properties (Song et al., 2009). Hence, this loop is closed through the restitution of used packaging to manufacturers for further production cycles.

The third circle links grain farmers and packaging manufacturers. Normally, cereal cultivation residues are downcycled within the farm. For instance, they can be scattered on the fields as mulch or used as bedding/low quality forage for livestock. In our model, these residues are considered a valuable starch source for packaging manufacturers for the extraction of PLA (Naveena et al., 2003; Maas et al., 2008). This loop is closed with used packaging, no longer suitable for further reuse due to overexploitation of its constituent material, being returned to grain farmers for compost. The fourth circle pertains to three actors in our model, namely retailers, insect breeders and livestock farmers. Unlike other loops, here circularity considers three material flows. Retailers provide insect breeders with bread residues (bread remaining unsold and consumer leftovers). Studies have been carried out into the possibility of breeding insects on organic substrates and organic waste (Diener et al., 2009; 2011). Furthermore insect species commonly used for waste recycling are among those used to produce edible proteins for livestock (*e.g. Tenebrio molitor*) (Ramos-Elorduy et al., 2002). In our model, insect breeders use bread residues as a feeding substrate for insects and sell their product to livestock farmers. Finally, the loop is closed with farmers providing retailers with meat or fish.

The fifth circle links retailers and consumers. Retailers sell bread and meat wrapped in PLA packaging to consumers. The loop is closed with the latter returning bread leftovers and used packaging to the former.

The sixth circle pertains only to consumers. In the linear model, consumers, except for domestic recycling, have no responsibility towards the product and may be considered mere intermediaries between retailers and waste collection companies. The circular economy is conceptually connected to the prospect of a cultural change in which consumers become responsible for the end-life of products. Other than returning materials to retailers, consumers should experiment with household reuse and recycling of organic matter. In order to pursue this aim, consumers need encouragement to change their habits. We imagine packaging with a recommendation on how to reuse and recycle materials. More specifically, appealing recipes made with bread leftovers and suggestions for garden composting of packaging could be used. For our packaging to be completely compostable, all its parts need to be made out of organic nutrients. This includes the labelling of the packaging, to be applied directly with biodegradable ink that can be easily washed off.

2.3 Results

From the analysis of the circular-based framework considered, we derived seven macro-categories that summarize the main challenges which actual implementation of our model would face: regulatory limitations; reverse cycle logistics management; geographic dispersion of enterprises; system boundaries and leakages of matter; acceptance among consumers; technology development and diffusion; uncertainty of investments and incentives.

2.3.1 Regulatory limitations

Our model considers the application of two radical technological innovations for the recycling of bread leftovers and packaging, namely insects as a source of animal feed and PLA packaging. These technologies are not well established in the market and regulations for their use still require fine tuning. Restrictions are observed on the use of insects in the livestock sector. Following the BSE (Bovine Spongiform Encephalopathy) outbreak, EC Regulation 999/2001 (EU, 2001) banned all PAPs (Processed Animal Proteins), except for hydrolysed proteins, from being used in animal feed. This prohibition was mitigated by EC Regulation 56/2013 (EU, 2013b) which allows proteins sourced from non-ruminants to be used at least in the aquaculture sector. Hence, regulatory developments supported by scientific evidence on the safe use of PAPs for other farmed animals are required. On the other hand, according to the nova-Institute (Nova-Institute, 2013), bio plastics in the packaging industry are promising. Given the huge impact of plastics used for traditional packaging on the environment and human health (Thompson et al., 2009), the rapid transition to more sustainable types of packaging is desirable. Hence, in order to facilitate this transition, legislation supporting the gradual phase-out of traditional plastic packaging could be a solution. With regard to the overall circularity of the model designed, in 2014 the European Commission adopted the communication *Towards a circular economy: a zero waste program for Europe* (EU, 2014) to establish a common and coherent EU framework to promote the circular economy. The program aims to: extend the lifetime of products; create markets for recyclable materials; reduce the use of non-recyclable materials; promote eco-design in order to facilitate maintenance, upgrade and remanufacture of products; incentivize the reduction and separate collection of waste by consumers; reduce greenhouse gas emissions and environmental impact. Nevertheless, there is still no exhaustive legislation concerning the circular economy in the agri-food supply chain of individual nations.

2.3.2 Reverse cycle logistics management

Reverse logistics chains need to be optimized from beginning to end. Our model envisages a number of material flows aimed at closing the loops. Other than the household recycling of materials, which is the only circle in which just one actor is engaged, the five remaining loops pertain to the exchange of materials between two or three actors. These flows are not part of the traditional supply chain of bread and need careful organization. More specifically, retailers should structure a system to collect bread leftovers and packaging from the consumers. Dedicated areas should be created to store materials prior to shipment to insect breeders and packaging manufacturers. Furthermore, for each material flow, agreements on which actors are in charge for the shipping of materials would be needed. The circular design thus requires cost-efficient and better quality collection and transportation systems. For this purpose, during the setting-up of reverse logistics, reverse truck routes should be considered. In the linear model, empty trucks undertake long trips after delivering products. This is extremely inefficient in terms of economic and environmental costs. Our model should take advantage of this inefficiency by using empty trips for the return of materials. Furthermore, collection systems should be located in areas accessible to end-of-life specialists and guarantee the preservation of quality and value of materials. Collection systems should also be consumer-friendly and be located in areas accessible to customers. Consumers should be incentivized to return materials through a system that is neither energy-intensive, costly nor time-consuming.

2.3.3 Geographic dispersion of enterprises

The model which we conceptualized is based on the reorganization of the current linear supply chain of bread. In the current system, connections among enterprises already exist and geographic distances can be considered the outcome of market mechanisms related to proximity and availability of resources (Chakrabarti and Mitchell, 2013). The circular model assumes the intervention of two more actors, namely insect breeders and livestock farmers. Moreover, packaging production should be relocated to an innovative company that produces PLA packaging. These new elements require an analysis of potential geographic limitations they could imply for the switch to the circular model. Livestock farmers are already supposed to provide retailers with their products. Hence, their intervention should not give cause for concern. On the other hand, insect breeders and compostable packaging manufacturers are new actors whose location could affect the efficiency of our model. With regard to insect breeders, this kind of business marks a radical innovation in the field of livestock nutrition. In spite of being traditionally used for both human and animal nutrition (DeFoliart, 1997), the interest in insects as a source of proteins in Western countries has started to grow only in the last few years (FAO, 2013b).

Hence, the insect-based industry is not yet well established and few countries are active in this field. Among these countries, in Europe, the Netherlands can be considered the leader and the main provider of insect proteins (Pascucci and De-Magistris, 2013). With regard to PLA packaging, the diffusion of this technology is strictly related to the expansion of the market of this

bio-based polymer. Although the installation of industrial scale PLA capacities in North America and Asia is already well-established, Europe's first industrial-scale PLA plant is far more recent (Nova-Institute, 2013). The restricted market for insects and PLA packaging would of course be a limitation for our model. Retailers would be limited in the provision of packaging and in the insect factory to which bread leftovers would be shipped, and such transactions could incur high transportation costs. Other than natural barriers related to geographic distances among companies, legal measures such as protectionist policies could represent a limit to trade. Within the European Union, TFEU (Arts. 28-37) (EU, 2012) allows free movement of goods and forbids quantitative restrictions between Member States. This means that there are no trade barriers among EU countries. Otherwise, in the case of trade with extra-EU countries, customs duties on imports and exports should be considered. Geographic dispersion of companies is thus a potential limit for the overall implementation of our circular model. Transportation costs and commercial duties among countries could negatively affect the economic efficiency of the *filière.* Furthermore, the negative externalities of transportation of materials have to be considered. Long trips made by trucks entail considerable impact in terms of greenhouse gas emissions. This would conflict with the principle of sustainability on which the concept of the circular economy is founded. As a consequence, for the purpose of making the switch to our circular model more economically viable, the expansion of the market for insects as a source of feed and of PLA is desirable. This would limit the dispersion of the enterprises involved in our model and reduce the economic and environmental costs related to geographic distances.

2.3.4 System boundaries and leakages of matter

The circular system we conceived involves a number of actors and material flows which we selected in order to close the main loops related to the production/consumption/reuse of bread. The complexity of the supply chain considered forced our analysis to exclude secondary steps in which some weaknesses (upstream, intermediate and downstream) could be identified. First, each company considered in our model needs further production inputs whose life cycle is still linear (upstream weakness). Grain farmers need tractors and a mill to produce flour, bread producers need ovens, packaging manufacturers need specific machinery, insect breeders need containers for rearing insects, livestock farmers need cowsheds or pens, and retailers need shelves. Furthermore, each materials flow entails shipments for which trucks are required. We did not calculate these items in the overall circularity of our model. Second, organic matter can perish during transportation and become unsuitable for the next steps of the supply chain (intermediate weakness). Inefficiency during transportation can cause deterioration of meat before it reaches the retailers or the loss of whole batches of cereals. This means potential leakages along the circular chain. Third, we did not consider other potential outputs of the system (downstream weaknesses). Livestock manure can be used as fertilizer or for the production of biofuels. Nevertheless, we did not consider these processes and the potential environmental impact generated by livestock slurry. Furthermore, household meat leftovers are not used as inputs for other processes because we assumed their amount to be limited. Furthermore, meat is not suitable for composting and European laws forbid the use of animal proteins as a feed source for livestock (EU, 2001). Downstream leakages contribute to limit the possibility of achieving a fully circular system in the supply chain considered.

The definition of system boundaries is unavoidable during the modelling process of a complex system like agri-food supply chains. According to Costanza et al. (1993), *'although almost any subdivision of the universe can be thought of as a system, modellers of systems usually look for boundaries that minimize the interaction between the system under study and the rest of the universe in order to make their job easier'*. Upstream and downstream weaknesses of our model are an obvious consequence of this law. Furthermore, intermediate weaknesses are related to inefficiencies that are often unpredictable. Nevertheless, in the long term, our model should be embedded in a broader and more efficient network of circular business in which waste is no longer produced.

2.3.5 Acceptance among consumers

Consumers are involved in two of the six loops considered in our model. They are supposed to return bread leftovers and used packaging to retailers. Otherwise, we assume that consumers can deal with household recycling/reuse of materials. They can reuse bread leftovers to make alternative culinary recipes and use packaging in their gardens as compostable substrate. This means that consumers should change their habits regarding the end-life of products. They should collect bread leftovers and used packaging in order to return them to retailers. Putting aside these materials and taking them back to their source requires an effort. Should consumers prefer to adopt the household reuse system we considered, they should feel engaged in recycling and enjoy cooking and gardening. Whether they wish to adopt the first or second solution, consumers should be incentivized to get involved in the circular system.

One of the main reasons for food waste during consumption in rich countries is that people can simply afford to waste food (FAO, 2011). Though there is growing social interest in ethical dimensions and sustainability issues related to food consumption (Cembalo et al., 2013), abundance and habits often lead consumers to feel no responsibility for their food waste. Hence, ensuring that people cooperate to create the circular model could require a significant effort. Education in schools and through mass media on the social and environmental consequences of food waste is needed. Furthermore, political initiatives aiming to spread ecological awareness would encourage the growth of psychological incentives among consumers to contribute to circularity. Nevertheless, education and environmental responsibility may not be sufficient to ensure consumers return products to retailers. Economic incentives like discounts on the purchase of other food products may be necessary.

2.3.6 Technology development and diffusion

The implementation of our model also depends on the development of the technologies considered. We assumed that insect breeders use bread leftovers as a feeding substrate for insects. Some studies about the possibility of breeding insects on organic substrates and organic waste have been carried out (Diener et al., 2009; 2011). Furthermore, we know that insect breeders in the Netherlands use specific organic substrates from various kinds of food residues. However, there are no studies about the use of bakery products for the nutrition of insects and the potential efficiency of this process has not yet been demonstrated. Even if bread leftovers have started to be used as a feeding substrate, the diffusion of know-how about the process would still require considerable effort. Moreover, the use of insects as a complement for livestock diets requires further competences. Insects are very important as feed for farmed animals, mainly in the poultry and aquaculture sectors (FAO, 2013b), and their nutritional composition has already been widely studied (Rumpold and Schlüter, 2013). Furthermore, insect species with a potential for recycling organic materials are among those used to produce edible proteins for livestock. In particular, they can be used to feed breed fish, poultry and swine (Newton et al., 1977; Ng et al., 2001; Ramos-Elorduy et al., 2002). However, further insights about the efficiency of such practices in the livestock industry and effects of insect proteins on meat production would be needed. As regards compostable packaging, bio plastic in the packaging industry is promising. PLA is already a well-known technology and, as early as 1845, this biopolymer was synthesized by the condensation of lactic acid (Auras et al., 2010). However, though the PLA industry is already a reality in North America and Asia, the installation of an European industrial-scale PLA capacity is far more recent (Nova-Institute, 2013). In order to have an impact on the market and to become price-competitive, scaling of production is needed. We imagined suggestions about recipes made with bread leftovers and about garden composting printed on compostable packaging. This information should be written with biodegradable ink. Biodegradability and compostability for inks are complex issues. Little is known in these areas and there are few scientific-based lifecycle analyses in the literature. According to the INX Green Team Sustainability (2015) the quantity of ink present on most packaging is so small that it does not affect the ability of substrates to biodegrade or compost. However, for our packaging to be completely compostable, careful investigation of sustainable non-toxic ink technologies suitable for PLA packaging is called for.

2.3.7 Uncertainty of investments and incentives

Our model assumes the commitment of firms in the application of new technologies and business models. This would entail the switch from traditional linear models to the circular one. Bread producers and grain farmers should stop the disposal of their production residues and return them to their respective loops. Livestock farmers should start to replace traditional plant sources of protein with insect-based sources. Retailers should stop the landfilling of bread residues and invest in systems for the collection, storage and shipping of bread leftovers and compostable packaging. Currently, the uncertain investment environment inhibits firms in the agri-food supply chain from investing in new technologies and in new business models. Unfortunately, the *'disposing is cheaper than using or re-using'* attitude is among the reasons leading to food waste in Western countries (FAO, 2011). Incentives to bear the risks related to innovative and sustainable businesses have to be created. The transition to a circular mode of operating requires innovative business solutions able to substitute existing ones to be profitable. Given the need to meet criteria of economic efficiency and environmental benefits simultaneously, public incentives for private activities are often a fundamental instrument (Turner et al., 1994; Cembalo, 2015). Along this line, the European Commission has instituted action and funding programs aimed at sustaining circular businesses. The *Life* Programme (EU, 2013c) is one of the core strategies to support pilot projects and best practices for the development of a circular economy.

Furthermore, in order to reach a broad implementation of our model, new ventures should start to operate in the industries of insects as feed and compostable packaging. Most entrepreneurs face huge difficulties in creating new companies. The failure rate of new ventures is in the most optimistic study estimated to be around 46% (Timmons and Spinelli, 2009). The creation of new ventures in the field of new products or processes can be even more difficult (Pascucci et al., 2015). However, the shift to the circular model in the supply chain considered requires first-mover firms and initiatives. Advantageous business models and initiatives could stimulate other entrepreneurs and could be imitated and expanded geographically.

2.4 Discussion and conclusions

The current paper described a potential alternative to the traditional supply chain of bread. Starting from the scheme of the present bread production/consumption model, a new one based on the principles of a circular economy was depicted. The model envisaged six circular interactions among seven actors (grain farmers, bread producers, retailers, compostable packaging manufacturers, insect breeders, livestock farmers, consumers) of the new approach to supply chains to achieve the ‘zero waste’ goal. In order to close the loops, two radical technological innovations, namely insects used as animal feed and PLA compostable packaging were considered. Seven macro-categories that summarized the main challenges to implementing the circular model were identified. We inferred from these macro-categories general conclusions for the whole agri-food sector. This inference is supported by two reasons. First, as five macro-categories (regulatory limitations, reverse cycles logistics management, system boundaries and leakages of matter, acceptance among consumers, uncertainty of investments and incentives) are not product/process specific, the reasoning made for the case of bread is worthy also for other value chains. Second, three macro-categories (regulatory limitations, geographic dispersion of enterprises, technology development and diffusion) are related to the implementation of new sustainable technologies that are still not well-known and spread. Given the poor diffusion of ecologic solutions able to address the problem of extracting the maximum value from agri-food waste, and assuming scientific and technological progress as the precondition for the realization of the circular economy, this second reason allows to draft broad conclusions. In the case of regulatory limitations, the generalization of this issue is justified by both the two reasons. Specific regulatory limitations related to new technologies are strictly linked to the effort institutions will make for the transition to the new model. Hence, we assumed these specific limitations being a starting point to highlight the need for legislative stimulation to the circular economy in the whole agri-food system.

The reviewed literature supports the idea that the implementation of a circular economy in the agri-food sector would reduce environmental and economic costs due to food waste disposal (Ellen MacArthur Foundation, 2012). Food waste can be used to produce feed, fertilizers, energy or as input for bio-refineries (Sugiura et al., 2009; Mirabella et al., 2014). Parfitt et al. (2010) suggest the development of closed-loop supply chain models to reduce food waste from its present high levels. More specifically, these authors claim *'food that is surplus to retailer or manufacturers, to be made available through alternative routes'*.

Our conceptual approach highlights the long path which the circular economy must travel down to become effective in agri-food supply chains. Despite the efforts of the EU to promote and finance new circular businesses (EU 2013c, 2014), specific regulation or lack of regulation still limits potential operational tools of circularity. Supply chains are still locked in traditional linear management systems. Hence, logistics for the reverse loops must be created. Efficient user-friendly collection and transportation systems must be implemented. More specifically, waste collection areas should be easily reachable from consumers and waste storage areas should be designed in order to quicken collection and transportation. The loss of organic matter along these processes is often unpredictable. Nevertheless, they must be planned in order to limit wastage of materials. Management systems must also be able to optimize material flows among enterprises that are located far apart. Indeed, geography is one of the main challenges for the circular economy. Technologies suitable for closing loops are still not well known or widespread. Furthermore, the uncertain investment environment inhibits firms in the agri-food supply chain from investing in new technologies and in new business models. Hence, the distribution of companies operating in new sustainable circular businesses is still sparse. Consumers also play a fundamental role for the circular economy. This may well entail a change in their consumption habits. They must be informed about the aims and benefits of a circular economy and be encouraged to get involved in the circular system. For instance, discounts or other types of monetary rewards to consumers that choose to participate to the circular system could be applied. Finally, in order to pursue the aim of a zero-waste economy in the agri-food supply chain, cross-sector collaborations must be created to limit the leakages of matter. These would allow to overcome the problem deriving from the definition of system boundaries. By connecting multiple value chains like the one described in this work, all materials fluxes could be embedded in a global circular system.

2.5 Current and future developments

The circular economy in the agri-food supply chain is still to be developed and significant efforts are still required in different areas. In order to provide more insights into the potential benefits of switching to the circular model and developing new circular solutions, the role of research is crucial. Furthermore, investors must be stimulated to change old business models. Starting from an improvement in the regulatory system and from the alignment of public economic incentives for private actors, institutions must pave the way towards the creation of a favorable environment for investment. Even more important is the cultural change that the revolution related to the circular economy entails. For this purpose, the role of public stakeholders is fundamental. Education in schools and through mass media on the social and environmental consequences of food waste are needed to spread awareness in society.

In our study an evident limitation was that our approach was merely conceptual. We based our research essentially on evidence inferred from the scientific literature. Hence, the modelling of the possible alternative supply chain is the outcome of intuition and intellectual speculation. An in-depth quanti-qualitative analysis of possible implications of the transition to the circular model would be needed. Moreover, a financial analysis of resources needed for the transition to the new model would add value in the domain of economic feasibility. A cross-country assessment of this feasibility related to current production systems, availability of technologies and social/cultural differences would be also desirable. However, both aspects fall outside the purpose of our research. Since circular economy is at an early stage (in academia), we tried to model an example of industrial symbiosis that falls in the domain of basic theory. It is aimed to provide a reference of how such a system could be structured, without a deep analysis of the multitude of different real contexts in which it could be implemented. Nevertheless, financial feasibility analysis represent fundamental future developments of research in the field of circular economy. Starting from the individuation of new business models and new technologies useful to accomplish the aim of ‘zero waste’, financial analysis of their cost effectiveness will be the step forward to the choice of the best solution. Furthermore, we limited our study to describe an outline of the supply chain of bread. In order to define circular interactions able to close the loops, we considered only the possible main actors of the new supply chain. Key connections encompassing the majority of material flows were included. Nevertheless, our model does not cover all potential sources of material losses such as transportation, and upstream and downstream leakages. With regard to the efficiency of the proposed solutions for the implementation of the new model in the value chain of bread, we didn’t consider alternatives to the ones identified. Also this limit is related to the purpose of our work. In order to conceptually address the threefold aim that, according with the core of our research, industrial society should accomplish (‘zero waste’, value chain restructuring and ‘cultural revolution’), we identified just one possible solution for the value chain under observation. Nevertheless, further research should incorporate comparative efficiency analysis of different innovative technologies (Yoon and Park, 2015) and alternative circular models usefully applied in the agri-food sector.

Chapter 3

CONSUMERS' PERSPECTIVE ON CIRCULAR ECONOMY STRATEGY FOR REDUCING FOOD WASTE

Abstract: Consumer behavior is strategic for restructuring supply chains through a sustainable circular economy. However, little is known about consumers' willingness to participate to circular economy. A structured questionnaire was submitted to a representative sample of Italian Households to assess consumers' willingness to be actively involved in a supply chain aiming at reducing food waste. Consumers are involved by returning their organic food waste to retailers in exchange for discounts on the purchase of animal products. The organic food waste returned enters in the production process of animal products. A choice experiment was designed to analyze alternative programs. Two scenarios where presented: one with a traditional technology (composting), and a second one with a radically innovative technology (insects as feed). Preferences and trade-offs, in monetary terms, among attributes were computed. Results depict a comprehensive portrait of the potential participation of consumers to supply chains grounded on the principles of circular economy.

Publication information: Borrello M., F. Caracciolo, A. Lombardi, S. Pascucci & L. Cembalo, 2016. Consumers' perspective on circular economy strategy for reducing food waste. - Paper candidate for the Best Paper Award at the IFAMA-WICaNeM 2016 Conference, and under revision of the International Food and Agribusiness Management Review (IFAMR).

3.1 Introduction

Post-industrial society is facing alarming global issues caused by the impacts of human activities on the environment. The call to *'not destroy the planet or make it absolutely uninhabitable'* (Hobsbawm, 1995) imposes a challenge that must be faced through new approaches to the economic system. However, current economic model is locked within traditional technologies, life styles, supply chains, as well as organizational, regulatory, institutional and political structures (Markard et al., 2012). The possibility to change this model entails the development of new strategies for the transition to sustainability. According to Markard et al. (2012), '*sustainability transitions are long-term, multi-dimensional, and fundamental transformation processes through which established socio-technical systems shift to more sustainable modes of production and consumption'.* Such transformations are radical and should be grounded on the investigation of the interdependence and co-evolution of economies and natural ecosystems over time and space. This investigation calls into question the established mainstream economy which has been defined as a systematically linear structure in which natural resources follow a 'cradle to grave' flow (*e.g.* McDonough and Braungart, 2002; Qiao and Qiao, 2013). Materials are extracted; they are used to produce goods; these goods are sold to customers; and eventually costumers dispose of the goods (or of their residues) at their end-life. Along this flow, namely the supply chain, waste and pollutants are produced, and huge amounts of materials that could be reused or recycled go lost, mainly landfilled. Since this system exceeds the capacity of our planet to regenerate resources and to absorb waste and pollutants, it is not bound to endure (Millennium Ecosystem Assessment, 2005). A sustainable economic system should instead try to emulate natural processes of the biosphere, according to the concept of bio-mimicry (Benyus, 2009). Biological materials move within ecosystems following continuous circular flows of matter and energy in which the idea of waste is not contemplated. To illustrate, dead leaves of a tree are decomposed and transformed into minerals that feed the tree for producing new leaves. This process is circular, so a circular economy could be a radical innovation able to integrate human activities into ecosystems (Ellen MacArthur Foundation, 2012).

Since economics try to let potential resources become real resources (Galimberti, 2004), new circular economy models might attempts to capitalize on the waste produced during linear life cycles. Circular economy is aimed to replace traditional linear supply chains with networks in which materials are recycled within production systems grounded on the principle 'waste=food'. This principle reinforces the common idea of recycling towards the up-cycling (Kenny et al., 2008), that refers to any process able to transform waste into higher value products by making it be inputs for other productions. To summarize, circular economy is planned in order to make *'someone's waste the resource of someone else'* (Borrello et al., 2016).

The need of shifting towards a circular economy has already been introduced in the agenda of international policy makers (EU 2015). However, this shift would be a sustainability transition that would encompass many areas and would face several challenges (Borrello et al., 2016). Some of these challenges concern society and, more specifically, consumers. In the linear economy, consumers are the last ring of supply chains. Their participation is confined to the mere purchase of products, as well as to the compliance to the rules of planned and perceived obsolescence (Latouche, 2009; Strausz, 2009). Thereby, they are passive and unaware in their condition of intermediaries between retailers and waste collection. Even though there are examples of final users (consumers) eventually actively involved in process innovation, it is a peculiarity of circular economy to engage consumers, as well as all the other actors of supply chains, in an active participation for the recycling of materials (Ellen MacArthur Foundation, 2013). Among materials through which consumers could participate to circular economy, food waste is one of the more concerning in terms of amounts produced (FAO, 2011). This work falls in this domain.

Wastages generated during late stages of food supply chains, namely during marketing and consumption, are considered food waste (Parfitt et al., 2010). Consumers in food unsecure countries are careful to not waste food. So, food waste is a peculiar phenomenon of western countries, where it is associated to ‘behavioral’ causes (HLPE, 2014). In this domain, consumer behavior gives a dramatic contribution to the food waste produced in developed countries (Stuart, 2009). Where abundance makes people able to afford wasting food, consumers deliberately choose to discard food still edible. Since circular supply chain models could be a method to reduce food waste from its present high levels (Parfitt et al., 2010; Pfaltzgraff et al., 2013; Mirabella et al., 2014), consumers could contribute by returning their household organic waste to retailers to let it re-circulate, or by purchasing circular food products. This kind of active consumer participation would be consistent with the increasing trend of consumers engaged in alternative food chains (Cembalo et al., 2015). Furthermore, the implementation of closed-loop systems involving consumers would ride the wave of the change in consumers’ attitudes towards green lifestyle (Cherian and Jacob, 2012). However, facing the consumers’ side of circular economy is still challenging. Circular economy assumes that consumers can deal with household recycling of materials. They should change their behavior regarding the end-life of products by collecting their waste in order to return it to producer/retailers. Putting aside these materials and taking them back to their source requires an effort involving commitment and responsibility. Furthermore, consumers should deal with new technologies used for recycling biological materials and closing the loop of food waste. Circular economy implies new strategies aimed to recycle materials through the use of innovative technologies (Ellen MacArthur Foundation, 2013). When it comes to agri-food supply chains these technologies have the potential to modify traditional processes used for the production of food. To illustrate, high added-value components - recovered from food waste and suited to food industry – can be extracted by means of new emerging technologies

(Galanakis, 2012). Consumer acceptance of a novel food technology is essential to its success and consumers are often skeptical about innovations in modern food production (Lusk et al., 2014). The scarce knowledge of new food technologies within society (Ronteltalp et al., 2007) and the cultural significance often associated to food products (Guerrero et al., 2010, Migliore et al., 2015) lead consumers to food neophobia. Thereby, food items that come from circular supply chains, could be perceived by consumers as risky and artificial.
This study is aimed to carry out a first assessment regarding the consumer dimension in the field of circular economy. To the best of our knowledge, no studies have explored so far the consumers‘ perspective of circular economy. Furthermore, possible implications of circular economy regarding the adoption of new technologies for the recycling of food waste have never been investigated. Our purpose is then to answer the following two questions: i. Are consumers willing to be actively involved in the circular economy?; and ii. Does the technology used for the recycling of organic food waste influence consumers' willingness? A questionnaire was administered to a representative sample of Italian Households (1,270 interviewees). We designed a hypothetical food circular supply chain that implied the participation of consumers through the restitution of their organic food waste to retailers through the subscription of a program that would work as an agreement between a consumer and a retailer. In a choice experiment, grounded on an efficient experimental design, respondents were asked to choose between alternative programs with varying attribute levels. Even though this mechanism might be interpreted as an operational tool for the management of households' organic food waste from supply chains, our rationale excludes any assumption regarding the feasibility and the potential effectiveness of the process described. The survey was instead aimed at capturing the propensity of consumers towards the principles of circular economy. More specifically, we wanted to study their willingness to actively participate to the supply chain through the commitment to a program

that engages consumers to the compliance of specific tasks concerning the recycling of organic food waste.
The relevance of this contribution falls in the importance of gaining knowledge about the consumers' dimension of the circular economy. Addressing the challenge of framing circular supply chains able to capture consumers' participation is not trivial task. If drivers influencing consumers' willingness to participate could be known, efficient prototypes of circular models could be implemented into the agri-food sector, as well as into other sectors. The commitment of consumers in new and demanding behaviors like the participation to the circular economy could be, thus, a starting point towards the transition to a more sustainable economy.

3.2 Framing of the technologies for recycling food waste

Circular economy tries to update the basic practice of recycling materials within natural ecosystems. For doing this, it introduces the concept of cascading, namely the diversified use of materials through consecutive production processes (Ellen MacArthur Foundation, 2013). Cascading happens by means of networks of factories in which organic by-products, instead of being landfilled or directly returned to the soil, are used as inputs of new productions. Thereby, food waste can become the substrate for feeding bio-refineries (Clark et al., 2012; Lin et al., 2013), where biological materials are converted by degrees into bio-chemicals, plastics, medicines and fuel through cascading processes. Among the alternatives for extracting the maximum value from food waste, the idea of making it re-circulate within food supply chains is fascinating. In this way, the ancient concept of soil restoration by returning food residues to the soil is updated with the use of food waste as input for the agri-food industry. To illustrate, food waste may be used as feed for livestock and fish (Cheng et al., 2014; San Martin et al., 2016), as human food (Toldrá et al., 2012), as well as for the production of fertilizers (Chiew et al., 2015; Tampio et al., 2015). For the purposes of this study, a traditional technology, namely composting, and another that is radically innovative, namely insects as animal feed, were compared in order to investigate the contribution of neophobia to consumers' perception of circular economy.

Composting is the production process of compost, the soil-like material generated through the aerobic decomposition of organic matter by organisms like bacteria, fungi, insects and earthworms. Since the usefulness of this process for generating stable products (Farrell and Jones, 2009), worldwide interest in using composting for recycling municipal solid waste is growing. Unlike the spread diffusion of composting, insects farming are a radically innovative method for recycling food waste. Insects are able to feed by using whatever organic material (Gullan and Cranston, 2005). More specifically, s*aprophagous* insects can feed on decaying organic matter and perform an essential role for the biosphere by contributing to the recycling of nutrients. In this field, satisfactory results about the possibility of breeding insects on organic substrates and organic waste have already been obtained (Diener et al., 2009; 2011). Furthermore, insects are able to convert embedded energy of decaying matter into complex organic molecules like proteins, suited to be fed to livestock and fish. In order to produce high value edible proteins within the framework of the circular economy, insects would allow to bypass biodegradation and production of vegetal proteins through the photosynthesis. Along this line, Premalatha et al. (2011) sharply affirm: it is a '*supreme irony'* that huge amounts of money are *'spent every year to save crops that contain no more than 14% of plant protein by killing another food source (insects) that may contain up to 75% of high-quality animal protein*'. Hence, starting from the idea that many kinds of insects are already part of the natural diet of farmed animals like chickens, pigs and fish (Gullan and Cranston, 2005), studies about the performances of this practice in the field of zootechnics have been arousing the interest of researchers in the last fifty years (Calvert et al., 1969; Makkar et al., 2014). This interest is also grounded on the fact that the main insect species suited for recycling waste are among those used to produce animal feed (Ramos-

Elorduy et al., 2002). Furthermore, international public institutions have been claiming the importance of insects as source of protein for livestock (FAO, 2013b). Thereby, business ventures are already farming insects to produce animal proteins from the recycling of materials generated from food supply chains. However, other than general skepticism of consumers regarding novel food technologies, in the case of insects, an additional criticism concerns socio-cultural barriers (Pascucci and De-Magistris, 2013). Insects are associated to their impact as vectors of diseases, as crop pests, as well as parasites of stored products. Furthermore, in western countries, repulsion and disgust are the typical attitudes towards insects (De-Foliart, 1999). As a consequence, even if there is *'a positive atmosphere and momentum'* (Verbeke et al., 2015) for the acceptance of insects as a new ingredient in animal feed, socio-cultural barriers could still limit their use for the recycling of food waste in the field of circular economy.

3.3 Data and Methods

3.3.1 The survey and the experimental design

A choice-based contingent experiment for a representative sample of 1,270 Italian Households (18-65 years old with balanced geographic distribution) was developed in order to: i. assess consumers' willingness to be actively involved in a circular economy framework; and ii. investigate the effect on consumers' choices of introducing a radical innovation related to a technology implemented in a circular economy supply chain. Data were collected through a structured questionnaire submitted through GFK, a global company that performs market and consumer studies.

The core of the survey concerned the investigation of consumers' preferences for a program regulating the participation in an hypothetical food circular supply chain, which implied the restitution of household organic food waste. Within each household, responsible of the purchases was selected for responding to the survey.

Consumers were informed that their organic food waste would have been used for the production of animal products. These products would have been sold at the same retail shop were consumers should have returned their waste. The choice experiment was aimed to analyze attributes of a program between consumers and the retailer. The questionnaire started with a clear explanation of the main features of circular economy to introduce the topic of the survey. The concept 'waste=food' was explained to highlight the relevance of circular production for reducing waste (Appendix A). The questionnaire was organized in three sections.

First section, the so-called warm-up, included questions aiming to understand whether interviewees were involved in household activities regarding food purchase and waste management.

In the second section interviewees were asked to make a choice among different programs alternatives. Two versions of the choice experiment were produced based on the two scenarios proposed (composting or insects as animal feed). Ten different choice tasks were developed for each version by means of a randomized choice-based conjoint (CBC) design approach with complete enumeration as provided by Sawtooth Software (1999). Respondents of each version were divided in two further groups to whom were administered two series of five choice tasks selected from the ten choice tasks developed through the CBC. Respondents were asked to perform a choice task between two alternative combinations of attribute levels (Table 5). Each alternative represents a program generated according to the CBC design[25]. Interviewees had the possibility to choose the most preferred program or to choose none of them. Scenarios were introduced with a general explanation of circular supply chains applied to agri-food system. Then, a detailed description of the

[25] In randomized CBC designs, each attribute level is equally likely to be included with each level of every other attribute. The complete enumeration assures that profiles are as nearly orthogonal as possible within households, and the frequencies of level combinations between attributes are equally balanced. The D-optimal coefficient of the experimental design resulted equal to 0.923.

Table 5. Selected attributes and levels of proposed programs.

Attributes	*Levels definition*
Monthly fixed discount	From 5 to 25 €, with 5 € intervals
Frequency of the delivery of organic waste	Number of deliveries of organic waste per week (once or twice a week)
Modality of the delivery of organic waste	Presence or absence of the collection at home of the organic waste
Duration of the participation to the program	From 6 months to 12 months
Penalization for the delivery of non-organic waste	Presence or absence of a reduction of the discount

hypothetical circular supply chain was provided. As mentioned earlier, two scenarios were randomly assigned to respondents so that two groups were generated. To the first group was presented a circular supply chain in which composting is used (Figure 15). In this supply chain, compost is meant to be a fertilizer to cultivate fodder crops for livestock and fish. To the second group was presented a circular supply chain that included the use of insects as animal feed (Figure 16) (Appendix A).

Interviewees were informed that their participation to the program would have implied the restitution to retailers of an amount of organic food waste proportionate to the number of the family members. In return, they would receive vouchers (discounts) for the purchase of animal products whose production process entails the use of the organic food waste returned. These products were eggs, pork meat, chicken meat, fresh farmed fish (salmon, sea-bass and sea-bream)[26]. The selected attributes, that in different level combinations formed the different program types proposed in the choice tasks, were accurately described so that respondents could make an informed choice. The

[26] These products were chosen since insects are part of the natural diet of the animals raised for the production of these products. The use of insects in the diet of farmed fish is already allowed by law, while it may be allowed in the near future for chickens and pigs. We chose these products also according to their degree of spread.

choice tasks were finally introduced highlighting that they represented hypothetical but realistic programs that could be offered in the future from Italian retailers. In the third section participants were asked to answer questions regarding their social, economic and demographic conditions.

Figure 15. Circular supply chain concerning the use of the technology ‘compost’ for recycling household food waste.

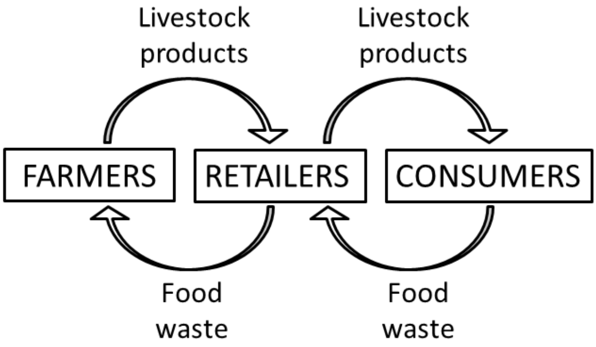
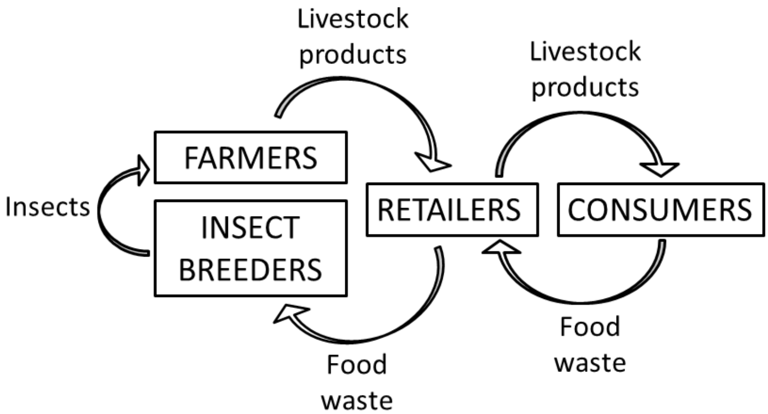


Figure 16. Circular supply chain concerning the use of the technology ‘insects as feed’ for recycling household food waste.



3.3.2 Descriptive statistics of the sample

The questionnaire was submitted to a representative sample of 1,270 Italian Households. Interviewees social, economic and demographic conditions collected were age, gender, household size, household role, education level, geographic origin, city size, socio-economic conditions. They were also asked if they are used to separate and dispose organic waste (Table 6). Respondents (202 males and 1068 females) were in the age range 21-65 years (47 ± 10) and living in middle-class (52.4%) medium-size households (3.13 ± 1.2 members). Most of respondents (92.7%) were the head of the family - or his (her) wife (husband). About a fourth of respondents held a university degree (24.33%). The sample was balanced according to the population distribution of Italy so that almost half of the respondents belonged to the north of the country (48.7%), followed by the south and the islands (35.4%) and then by the center (15.9%). As regards the city size, no categories prevailed noticeably. However, more than 45% of respondents belonged to medium size cities (categories 3 and 4). The questionnaire revealed also that a high percentage of the sample (88%) already used to sort their household organic food waste (also known as humid waste).

3.3.3 Empirical model

The empirical framework adopted has its theoretical foundations in the random utility theory (RUM) of McFadden (2001). It follows previous studies that analyze preferences for contract attributes such as Roe et al. (2004) and Cembalo et al. (2014) among others. The framework supposes that when *J* program alternatives are showed to the *i-th* consumer, the utility assigned by the consumer to each *j*-th program alternative is a linear, additive, and separable function of all *c-th* attributes that constitutes the contract:

$$U^i_j = f^i(\mathbf{x}_j) + \varepsilon^i_j \tag{1}$$

where $\mathbf{x}_j$ is a vector of observed attributes characterizing the *j*-contract.

In RUM, the program alternative chosen *j* represents the outcome of an expected utility maximization exercise of the household. The random utility model considers utility $U^i{}_j$ equal to the sum of an observable component $\boldsymbol{B}\mathbf{x}_j$ and the stochastic component ε_j, with $\boldsymbol{B}$ as vector of unknown parameters that could be assumed constant (fixed parameter model) or varying (random parameter model) across consumers (eq 2).

(2) $$U^i{}_j = \boldsymbol{B}^i\mathbf{x}_j, + \varepsilon^i_j$$

In the latter case, distribution of each $\boldsymbol{B}^i$ may follow a probability distribution function. Generally it is distributed as normal, $N \sim (\tau, \sigma^2)$, relaxing the i.i.d. assumption on the error terms (Train 2003).

Estimates of $\boldsymbol{B}$ parameters can be obtained through the maximum likelihood estimator (Train, 2003), with τ indicating the mean value of the distribution function of the parameter. The greater the value of τ, the greater will be the preference for the consumers for that attribute of the contract (if statistically significant). Estimates of σ^2 show the variability of the preferences toward each contract attribute across the consumers.

3.4 Results

Data on consumers' responses to the choice tasks have been analyzed with a conditional logit model with both random and fixed parameters. Results are reported in Table 7.

According to the model results, the only program attribute consumers did not consider in their choices is the duration of the participation to the program. The coefficient is indeed not statistically significant. The model also provides statistical evidence that consumers clearly prefer a high discount, low frequency, the absence of a penalization and the presence of the collection at home of the organic food waste.

Table 6. Descriptive statistics of consumers interviewed

Description		*Mean*	*Std.dev*	*Min*	*Max*
Age	(year)	46.87	9.916	21	65
Gender	1 if female 0 otherwise	0.841		0	1
Household size		3.135	1.198	1	9
Household role					
	Head of the family (or spouse)	92.7%			
	Son/daughter	6.7%			
	Others	0.6%			
Education level		2.93	0.786	1	4
	1 primary	3.31%			
	2 secondary	24.57%			
	3 high school	47.80%			
	4 university	24.33%			
Geographic origin					
	North	48.7%			
	Center	15.9%			
	South and islands	35.4%			
City size		3.29	1.568	1	6
	1 less than 5,000 inhabitants	17.64%			
	2 more than 5,000 and less than10,000	14.17%			
	3 more than 10,000 and less than 30,000	23.54%			
	4 more than 30,000 and less than 100,000	21.97%			
	5 more than 100,000 and less than 500,000	11.34%			
	6 more than 500,000 inhabitants	11.34%			
Socio-economic classes		3.37	1.068	1	6
	1 lower class	9.38%			
	2 working class	10.01%			
	3 lower middle class	21.91%			
	4 middle class	52.40%			
	5 upper middle class	5.83%			
	6 upper class	0.47%			
Humid waste	1 if already sorting organic waste; 0 otherwise	0.88		0	1

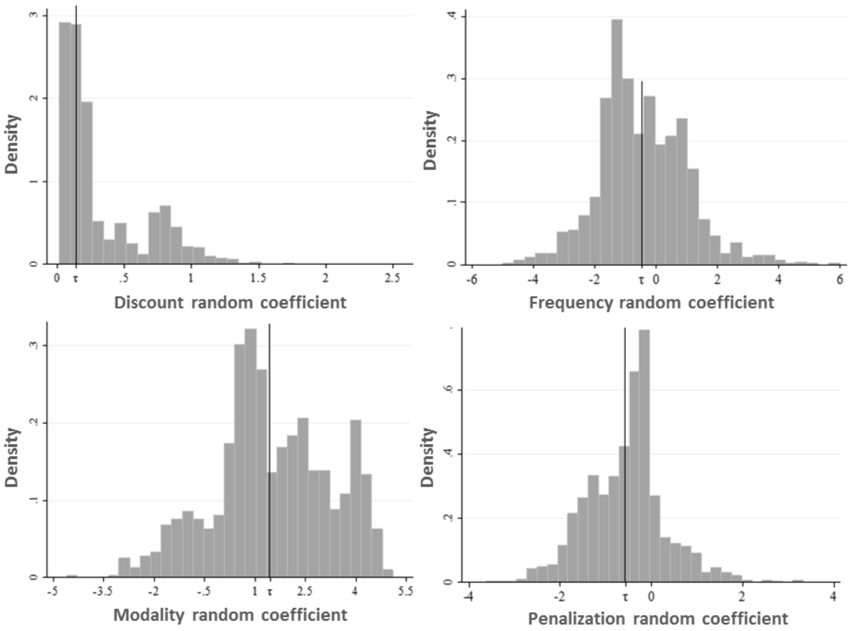
From these results, some indications, in monetary terms, can be obtained on the trade-off consumers' made between the attributes and the discount (Coeff./Coeff.$_{discount}$, in the third column of Table 7). The modality of the delivering of organic waste has a discount premium estimated equal to €9.84 per month for receiving the service of collection at home. Delivering the organic food waste with a higher frequency and having a penalization for the delivery of non-organic food waste are considered by consumers as a loss. Thereby, consumers would ask an additional discount of €2.12 for delivering food waste twice a week and an additional discount of €2.39 for subscribing a program with the penalization.

Table 7. Conditional logit results.

	Fixed Parameters			*Random Parameters*			
	Coeff.	*p-value*	*WTP*	*Coeff. (τ)*	*p-value*	*Coeff. (σ)*	*p-value*
Discount	0.096	0	1	0.141	0	0.095	0
Frequency	-0.204	0	-2.1	-0.469	0	2.271	0
Modality	0.948	0	9.84	1.447	0	2.338	0
Duration	-0.013	0.732	-0.1	-0.026	0.649		
Penalization	-0.23	0	-2.4	-0.567	0	1.421	0
Opt out	0.184	0.012		0.762	0		

Results of the random parameters conditional logit show heterogeneity within parameters that may be discussed through the graphics in Figure 17. The graphics show the heterogeneity of the distribution of the four statistically significant parameters. Here, we discuss the heterogeneity of the parameter 'Modality', which we observed to be the most important among the attributes considered. The coefficient of this parameter has the value 1.447 (fourth column of Table 7), meaning that respondents preferred programs having the service of collection at home of the organic food waste. However, the graphic in Figure 17 concerning this parameter demonstrates that part of the respondents are willing to deliver personally the waste. The

Figure 17. Distribution of random parameters.



correlation matrix of random parameters (Table 8) shows that the parameter 'Modality' is positively correlated with the one 'Frequency' and negatively correlated with the one 'Discount'. This means that interviewees willing to deliver personally the waste are often also the same willing to deliver it twice a week and less attached to the discount. We assume that this part of the sample is representative of respondents who are more willing to be committed in the mechanism presented.

A probit model was implemented in order to characterize respondents that are willing to deliver personally the organic food waste to retailers (positive coefficient for the parameter 'Modality'). Results of the probit show that the probability that the parameter 'Modality' is positive increases if respondents are female, young and highly educated (Table 9). Furthermore, respondents that were used to differentiate organic food waste show a higher probability to be willing to deliver it personally.

Table 10 shows the number of consumers that refused to participate to both programs for the five choice tasks. A high percentage of interviewees (78.9%) accepted to participate to one of the two programs for all choice tasks, whereas only 6.61% of respondents accepted none. Our outcomes show that the treatment had very scarce effect on the choices of respondents. The percentage of consumers who refused to participate to both programs is similar for the treatment with compost and for the one with insects (second and fourth column of Table 10). Treatments had no influence on the factors of the participation, so likely they did not influence the point of view of consumers about the programs.

Table 8. Correlation matrix of random parameters.

	Frequency	*Modality*	*Penalization*	*Discount*
Frequency	1			
Modality	0.0859***	1		
Penalization	-0.0502*	0.0278	1	
Discount	0.0551**	-0.1069***	0.1585***	1

Table 9. Probit model. Dependent variable positive coefficient for the parameter ‘Modality’.

Variable	*Coeff.*	*p-value*
Economic classes	-0.022	0.601
Organic waste	**0.276**	**0.030**
Gender (1= female)	**0.292**	**0.011**
Age	**-0.012**	**0.012**
Educational level	**0.150**	**0.013**
Household size	-0.032	0.396
City size	-0.039	0.181
South of Italy	0.078	0.417
_cons	0.952	0.034

Table 10. Respondents who rejected both programs.

	Treatment with compost		*Treatment with insects*		*Total*	
Number of refusals	*Value*	*Percentage*	*Value*	*Percentage*	*Value*	*Percentage*
0	429	79.59	573	78.39	1002	78.90
1	27	5.01	44	6.02	71	5.59
2	26	4.82	26	3.56	52	4.09
3	14	2.6	23	3.15	37	2.91
4	7	1.3	17	2.33	24	1.89
5	36	6.68	48	6.57	84	6.61
	539		731		1270	

3.5 Discussion and conclusions

Circular economy attempts to reorganize supply chains in order to reduce the impact of human activities on the environment. In this paper we carried out an assessment on the consumers side of circular economy. For doing this we framed a case study in the domain of agri-food supply chains. Household organic food waste is a biological material that has high potential for being reused within the framework of the circular economy. Thereby, we designed a realistic, though hypothetical, circular supply chain for the production of animal food products which implied the participation of consumers through the restitution to retailers of their organic food waste. With no pretence of deviating into the field of waste management, we aimed to elicit knowledge concerning the attitude of consumers towards the idea of actively participate to the circular economy. For this purpose, we submitted a structured questionnaire to a representative sample of Italian Households. A choice experiment in which consumers were asked to express their preferences about the attributes of a participation program to the abovementioned circular supply chain was implemented. The sample was split in two groups in order to assess the potential influence of different technologies to the participation to the program. A traditional technology (composting) and a radical innovative one (insects as feed), both suitable for

recycling organic food waste in the framework of animal food productions, were presented.
A high proportion of respondents reacted positively to the scenario presented during the experiment. Most of them never rejected both the alternative programs proposed in the five choice tasks of the questionnaire. The treatment concerning the technology used for the recycling of organic food waste had almost no effect on the choices of the interviewees. Respondents declared to be willing to participate to the circular supply chain according to similar percentages for both the scenario with compost and the scenario with insects. This pattern let us to reject the hypothesis that food neophobia could have influenced consumers' attitude towards participation. Even though repulsion for insects is a determinant in the current scientific debate, when it comes to circular economy consumers' position seems to be more influenced from drivers more proximate to the participation itself. Attributes of the program had indeed clear effects in determining consumers' choices. The increasing of the discount for purchasing the animal products proposed by the program affected positively the participation. This is consistent with the assumption that consumers want to be rewarded for the effort required from circular economy. As a consequence, consumers showed also to prefer programs in which they did not risk to have a lower discount due to the delivery of non-organic waste. Consumers' attitude towards a penalization let us also to suppose that the proper collection of organic waste for recycling could be not an easy task. The responses to the choice tasks revealed also that consumers would prefer to limit the effort related to the participation. First, they reacted negatively to programs in which they should have delivered more frequently the organic food waste to retailers. Second, the analysis of trade-offs in monetary terms among contract attributes suggests that consumers would give away a big part of the discount in exchange for the collection at home of the organic food waste. Nevertheless, part of the respondents resulted to be more willing to be committed in the mechanism proposed by the experiment irrespective of any rewards and efforts. These respondents declared to

be willing to deliver personally the organic waste to retailers, to have no problems in doing it twice a week, as well as to not being attached to the compensation through the discount. The analysis of this part of the sample let us to infer a potential portrait of the participant to the circular supply chain designed: ‘a young and educated woman who is already experienced with organic waste collection’.

The outcomes of this study help to derive some conclusion regarding the peculiarity of a circular economy framework, that is consumers actively involved in the mechanisms of the circular economy. We assumed that consumers’ position in the linear model of supply chain is worthy of blame. However, consistently with the recent literature on the green evolution of consumer behavior, our experiment shows that many consumers would be willing, if sufficiently rewarded, to be committed within a circular supply chain that entails their active participation. Moreover, part of our sample shows the existence of a segment of Italian population that is more willing to make personal efforts for the cause of the circular economy and that is less attached to the concept of monetary compensation. This result gets along with recent efforts of policy makers concerning the development of a circular economy for contrasting waste production and reducing the extraction of natural resources. Moreover, it provides both incentives and insights for stakeholders willing to replicate into the field a circular supply chain similar to the one described in this paper. We are conscious that our choice of food waste for testing consumers’ attitudes is a constraint for an immediate practical scalability of our model. The literature on food waste management is rich and we did not analyze the potential effectiveness and feasibility of our design. However, the positive attitude showed by consumers for participation through the recycling of a perishable material like organic food waste make our conclusions rationally worthy of being generalized to other materials recyclable through the circular economy. This research also contributes to the increasing literature regarding consumers’ acceptability of insects in the domain of human and livestock nutrition. Even though the treatment with insects had no effects in determining consumers choice, we might hypothesize that the insects ‘yuck factor’ is not strong enough to affect their opinion about participation to the circular model.

Further research is needed in this field of inquiry. Our purpose was to give a contribution to the knowledge on the consumer dimension of the circular economy. Nevertheless, even though models of implemented circular economy are still rare, investigations concerning consumers’ behavior when it comes to really guarantee their commitment would be needed. Furthermore, assessing the position of other potential stakeholders of the circular economy, like the retailers, is necessary for addressing other challenges related to the implementation of the new model. Eventually, research on the logistics of the supply chain proposed would make our model worthy of being considered as a solution in the field of food waste management.

Chapter 4

SUMMARY OF MAIN FINDINGS

This study investigates the domain of the circular economy and some of its implications for the agri-food sector. The aim of this research is to provide a conceptual outline of the principles of the circular economy and to discuss possible implications of the new model for agri-food supply chains. More specifically, through the design of two hypothetical circular supply chains, we sought to: i. highlight major barriers to achieving a transition into a circular economy in the agri-food sector; and ii. assess the consumers' willingness to be actively involved in the new model. Results are meant to outline main features of the landscape in which stakeholders intending to lend their contribution to the implementation of the circular economy in the agri-food sector would operate. Furthermore we have tried to profile the type consumer to which new strategies of supply chain based on the principles of the circular economy could be directed.

In chapter 1, a literature review was used to conceptualize the circular economy and its potential for creating agri-food circular supply chains based on the up-cycling of food losses and waste. In paragraph 1.1 we sought to revisit the context in which the idea of circular economy was developed. The literature review was used to outline the main impacts of the current model of production-consumption on the environment and on the society at large. Here, this model is described as linear. Ecological economics paradigm was individuated as starting point for the evolution of some schools of thought aimed to find the way for a long-lasting equilibrium of human activities within the environment. In paragraph 1.2 the circular economy is introduced and the literature was used to describe the main characteristics of the new model. Circular economy promotes a complete recycling of materials and involves a complete reorganization of productions in which all steps of value chains are intended to use waste as input of new production processes. Moreover, the circular economy is based on a set of principles that are aimed to re-conceptualize the way we think to supply chains and to valorize the idea of extracting the maximum value from resources. Some of these principles can be summarized as follows: ‘reduce, reuse and recycle’, ‘waste=food’, ‘participation of consumers’ ‘cascading’, ‘up-cycling’, and ‘eco-effectiveness’. Eventually, food losses and waste are introduced as biological materials that have high prospective for being recycled in the domain of the circular economy. Paragraph 1.3 is a review of main questions concerning food losses and waste produced during agri-food supply chains. Approximately 1.3 billion metric tons of food is lost or wasted every year worldwide. As regards as rich countries, literature showed the significance of food waste, namely the amount of food that goes thrown away during distribution and consumption. Findings highlight the importance of considering food waste within the framework of the circular economy.

Chapter 2 describes a study regarding a hypothetical circular alternative to the traditional supply chain of bread that entails the use of two radical technological innovations (PLA packaging and insect as feed). The study used a conceptual approach to define the main challenges for the transition to the circular economy in the agri-food sector. We concluded that circular agri-food supply chain are still to be developed and significant efforts are still required in different areas. From the analysis of the circular-based framework considered, we derived seven macro-categories of challenges: regulatory limitations; reverse cycle logistics management; geographic dispersion of enterprises; system boundaries and leakages of matter; acceptance among consumers; technology development and diffusion; uncertainty of investments and incentives. Even though international institutions are already encouraging and financing new circular businesses, current model of production-consumption is still strongly conditioned by the established structure of the linear economy. Old technologies, life styles, supply chains, as well as organizational and regulatory structures are the main constraints that the circular economy will face in the near future. Starting from the reinforcement of regulation promoting the new model and from the alignment of public economic incentives for private actors, institutions must facilitate the creation of a advantageous environment for investments. Investments should be aimed to support the development of new circular connections among enterprises and for the development and the diffusion of innovative technologies for closing the loops. Even more important is the cultural transformation that circular economy entails in order to make consumers switching from the concept of 'ownership' to that of 'user-ship'.

Chapter 3 proposes a study aimed to capture - through a questionnaire submitted to 1,270 Italian Households - the consumers' willingness to be actively involved in the circular economy. We considered a realistic, though hypothetical, circular supply chain for the production of animal food products which based on the participation of consumers through the restitution to retailers of their organic food waste. The organic food waste returned is recycled within the production process of animal products. A choice experiment was organized to examine alternative programs of participation. Two scenarios where presented: one with a traditional technology (composting), and a second one with a radically innovative technology (insects as feed) used for the recycling of the organic food waste. However, the treatment concerning the technology used for the recycling of organic food waste had almost no effect on the choices of the respondents. Results are consistent with the hypothesis that consumers prefer programs that entails high discounts and low personal effort. Nevertheless, results showed that a high proportion of consumers would be willing, if sufficiently compensated, to be engaged within a circular supply chain that involves their active participation. Moreover, part of our sample shows the existence of a segment of Italian population that is more willing to make personal efforts for the cause of the circular economy and that is less attached to monetary rewards. The positive attitude showed by consumers for participation through the recycling of a perishable material like organic food waste make our conclusions rationally worthy of being extended to other materials recyclable through the circular economy.

Final remark

Circular economy has the potential of becoming a revolution in the history of economic development models. This study has demonstrated the strength of the principles on which the circular economy is grounded for achieving sustainability in the agri-food sector by aspiring to an economy intended as a subfield of the environment. However, organizational and cultural implications of the new model make us infer that an economy structured in loops is not a perspective achievable in the short run.

Despite the challenges revealed from our research, some evidences of a substratum on which building the basis for the transition to the circular economy exist. Scattered companies are already experimenting prototypes of circular supply chains and an important part of consumers show to be willing to take part to such initiatives.

Starting from these considerations, we believe that the support of both institutions and research is fundamental. Institutions have the task of creating the organizational and cultural environment in which circular entrepreneurship could be implemented. Eventually, the role of research in the near future will be crucial for the development of efficient and effective circular solutions.

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APPENDIX A – the questionnaire

University of Naples Federico II, Italy

Dear Sir/Madam,

Today we propose you to participate to a survey carried out from the University of Naples Federico II about circular production methods in the agri-food sector. Circular production methods are grounded on the complete reuse of scraps and waste generated from production and distribution of products. In the case of agri-food products, these methods are based on the use of organic productions, biodegradable or compostable packaging, as well as on the use of solar and/or renewable energy. Moreover, all circular products are realized following ethic and responsibility production models.

The questionnaire is strictly anonymous. The information collected will be treated through an aggregate analysis and the results will be used only for scientific or educational objectives from the University of Naples Federico II. For this purpose, we would ask you to devote about 15 minutes of your time to fill in the questionnaire below. There are no right or wrong answers: what counts for us is your opinion.

INTRODUCTIVE QUESTIONS

- Are you the one who mainly manages the purchase of food in your family?

□ Yes
□ No

- Are you the one who mainly manages domestic food waste in your family?

□ Yes
□ No

- Does your family collect items for recycling?
- □ Yes
- □ No
- Does your family recycle organic waste?
- □ Yes
- □ No

SECTION 1 – EXPERIMENT: Participation to a project of food circular economy

Current systems of food production and consumption generate an overexploitation of natural resources and huge food wastages. Some institutions and some researchers propose to replace the current model with another one aimed both to reduce the consumption of resources and to eliminate the production of waste. This model implies the creation of networks in which the waste of some enterprises are used as production inputs from other enterprises (circular supply chains). Within the circular model, consumers can have an active role. Now you will be introduced to a method of circular supply chain that could be proposed to Italians in the future.

- <u>Treatment with compost (Scenario 1)</u>

During distribution and consumption of food products, huge amounts of food waste is generated. The University of Naples Federico II and an Italian big chain of supermarkets have created a method to eliminate organic waste through the reuse within the food chain. This method implies that domestic organic waste is reused through composting. This compost is used as organic matter within farms that produce feed for chickens, pigs and farmed fish. Compost improves soil fertility and can be used to replace chemical fertilizers in order to have positive effects on the environment. Consumers participate to this model by returning to supermarkets their organic waste. This waste, after being inspected, is added to the waste generated from supermarkets. Consumers who accept to participate are repaid through a discount for the purchase of animal products obtained by means of the circular method. These products are chicken, pork, fish and eggs that generated from this cooperation.

- <u>Treatment with insects (Scenario 2)</u>

During distribution and consumption of food products, huge amounts of food waste is generated. The University of Naples Federico II and an Italian big chain of supermarkets have created a method to eliminate organic waste through the reuse within the food chain. This method implies that domestic organic waste is reused as feeding substrate for insects which, in turn, are used as feed for chickens, pigs and farmed fish. The use of insects as feed, other than being part of the natural behavior of some animals, is a top source of nutrients. Insects have low environmental impact and a great potential in the feed sector. Consumers participate to this model by returning to supermarkets their organic waste. This waste, after being inspected, are added to the waste generated from supermarkets. Consumers who accept to participate are repaid through a discount for the purchase of animal products obtained by means of the circular method. These products are chicken, pork, fish and eggs that generated from this cooperation.

Please, assume to be asked to participate to a program. This program entails to obtain discounts for the purchase of some selected food products in return for the restitution of an amount of organic waste. This amount can fluctuate from 1 up to 5 kg per week according to the number of components of your family. Discounts concern the purchase of eggs, fresh pork or chicken, as well as fresh farmed fish lime salmon, sea-bass and sea-bream.

Factors on which the proposal of participation to the project of circular economy is based – and on which please focus your attention – are the following:

- DISCOUNT: consumers who accept to participate receives a fixed monthly discount, that can be spent as a coupon, for the purchase of the abovementioned products. The discount fluctuates according to both the frequency and the modality of the delivery of the organic waste, as well as to the duration of the participation.
- FREQUENCY OF THE DELIVERING: the weekly commitment of the participant to deliver the organic waste (once or twice a week).
- MODALITY OF THE DELIVERING: the modality of the delivering of the organic waste from the participant. It can be executed in two ways: 1. direct delivery to the supermarket; 2. collection at home from the supermarket.
- DURATION OF THE PARTICIPATION: the duration in number of months of the participation to the program.
- PENALIZATION FOR THE DELIVERY OF NON-ORGANIC WASTE: reduction, down to the annulment of the discount, if the organic waste delivered from the participant contains in part mixed or non-organic waste.

Now, we will show you a set of possible participation programs that could regulate the relationship between the participant and the supermarket.

Programs will be showed in pairs and will be indicated as **proposal A** and **proposal B**.

For each pairs, please focus your attention on the conditions implied for each factors, and choose the proposal that you prefer.

Please, consider the following pair of proposals.

Which program do you prefer?

- □ Proposal A
- □ Proposal B
- □ None

Curriculum vitae

Massimiliano Borrello was born in Naples (Italy) on March 11, 1987. He joined the University of Naples Federico II in Italy where he took his bachelor degree in 2009 and his master of science in 2011, major in Forestry and Environmental Sciences. After an internship at the NGO Forest Friends (Ireland), in 2012 he got the opportunity to do his PhD at the Department of Agricultural Sciences, Agricultural Economics and Policy Group, of the University of Naples Federico II (Italy). During his PhD, Massimiliano was invited as visiting scholar by the Management Studies Group at the Wageningen University (The Netherlands). Massimiliano has also been active in national and international conferences where he was involved in presenting several scientific works related to the subject of his PhD. In the process, he managed to publish some of his PhD researches in internationally peer-reviewed journals.

Doctoral thesis:
XXVII PhD program in management and valorization of agroforestry resources

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